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Echo Sounding Experiments in the Barents Sea

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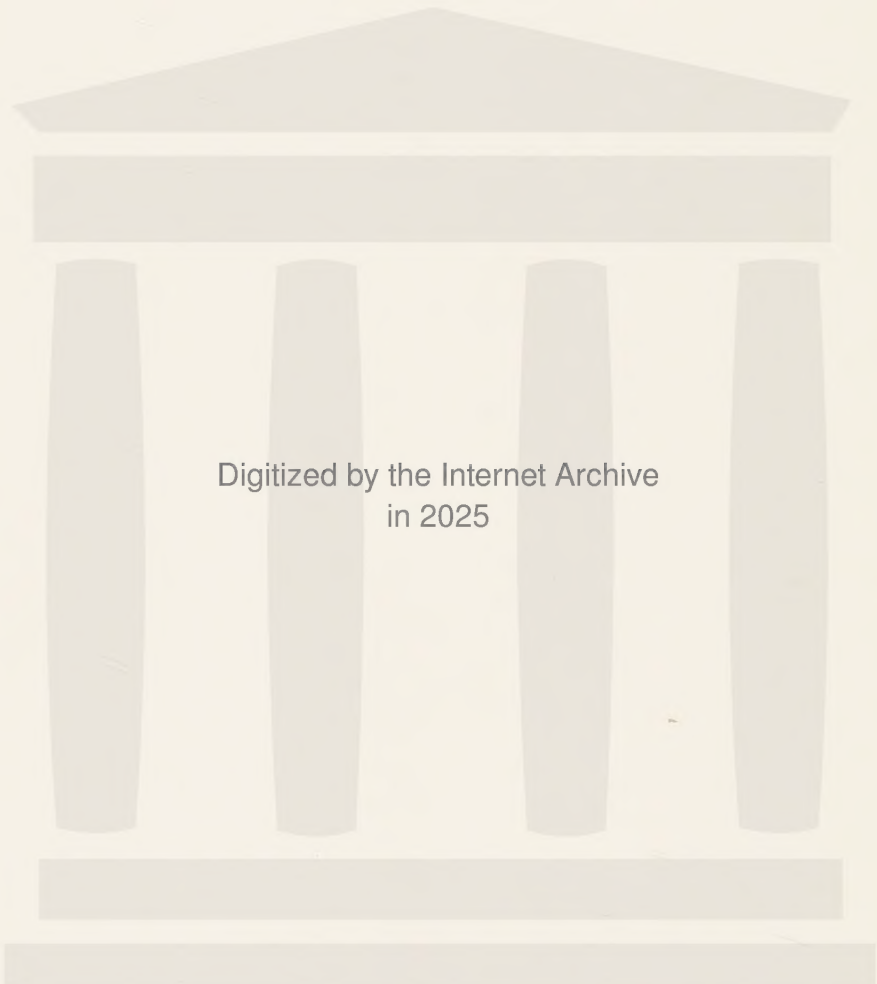

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PREFACE

THE use of echo sounding as a method of finding shoals of pelagic fish such as the herring is now a well accepted routine of drifter fishermen in all European seas. As yet, however, there is no certain identification of the various kinds of fish that give the echo, nor is there any other than a crude and arbitrary estimate of the density of the shoals that give rise to these echoes. Surveys of herring grounds and the plotting of the number of echoes per mile from the paper records have, however, given most useful indications of the extent and location of the shoals for the guidance of fishermen. Moreover, the comparison of these plotted areas with the catches has helped to give an estimate, not only of the quantitative equivalence of herring to echo traces in the areas where both are found but to extend this estimate to areas in which traces occurred but no fishing.

To match this progress in the pelagic field with corresponding work on trawl-caught fish presents special difficulties and the present studies constitute an account of how a first effort has been made to use the method of echo sounding in order to detect and enumerate a common and most important trawl-caught fish—the Arctic cod.

As with pelagic fish the first approach, outlined in Mr. Richardson's section, has been largely empirical. The method has then been subjected to more precise analysis by Dr. Cushing, Dr. Harden Jones and Messrs. Beverton and Blacker, and finally Dr. Cushing has worked out a technique of survey with the ship running at her full cruising speed.

The detection and forecasting during trawling and the echo-survey at speed have both given results which were repeatable and consistent, so that there is no doubt that now we have available another improvement in the efficiency with which our distant-water trawlers may carry out their job. The effect should be to reduce the time required to locate cod shoals at payable levels and thus to shorten the voyages and reduce the overhead expenses of these costly vessels.

The cathode ray oscilloscope method of presenting the returned signal has played an important part in the investigations and the equipment used for most of the observations was a Kelvin Hughes MS 24 30 kc/s sounder having a pulse initiated with an inductive charger. The returned signals were displayed on an A. scan cathode ray tube. For part of the work a Pye 'Fishfinder' 30 kc/s sounder having cathode ray tube presentation was also used. Here the pulse was initiated with a valve oscillator.

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Lowestoft.
15th May, 1958.

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Echo Sounding Experiments in the Barents Sea

I. PROBLEMS OF ECHO-DETECTION OF COD IN THE BEAR ISLAND REGION

by I. D. Richardson

INTRODUCTION

DURING the past few years, various types of traces attributed to fish have been obtained on the ERNEST HOLT, using commercial paper-recording echo sounders. On some cruises, particularly the summer ones, traces which have been attributed to cod have been obtained frequently (Graham *et. al*, 1954). These traces have rarely been correlated with large catches of cod, whereas good paying quantities of fish have been taken when little or no trace has been recorded on the paper.

It was thought that the method of recording on paper was probably at fault in that it was incapable of distinguishing fish within a fathom of the sea-bed and within reach of the trawl, but showed clearly fish off the bottom which were mainly above the trawl and therefore not caught. An echo sounder having a cathode ray tube presentation was used on an exploratory cruise in May–June, 1955 to find out whether fish echoes could be observed on the CRT (cathode ray tube) which were not recorded on the echo paper, and if it were possible to correlate the amount of echo observed during a tow with the quantity of fish taken by the trawl.

In the model used for most of this work, the range setting could be adjusted to give a scan of 15, 10 or 5 fathoms, i.e. from top to bottom of the screen. As it was not known how close the fish must be to the sea-bed to be caught by the trawl, i.e. within the last fathom, the last two fathoms, etc., the 10-fathoms range setting was used on the first cruise, but as the operators gained more experience on the disposition of echoes it became apparent that most fish were within two fathoms of the bottom and therefore the larger scale, or screen range of 5 fathoms, could be used successfully in later cruises. This 5-fathoms scale has obvious advantages in giving a larger picture of echoes, a feature which is particularly important when trying to distinguish the various types of echo, but its usefulness is offset by the need for considerably more manipulation of the depth control to keep the sea-bed echo on the screen when steaming over rough ground.

The spot of light runs from the top of the tube to the bottom, moving laterally whenever echoes are received; due to the persistence of the screen, this appears as a band of light, known as the time-base, down the centre of the screen, which broadens laterally according to the amplitude of the signal received. On high amplifier settings, the time-base becomes feathery in appearance but by adjusting the setting, these amplitudes on either side of the time-base can be reduced until they can still be seen, but at a minimum. This was the amplifier setting which was used throughout the cruise, i.e. when noise, the cause of these markings, was reduced to an extent which could be neglected. Any echo of amplitude slightly greater than the noise-level could be seen clearly. The amount of noise alters under varying conditions of speed and depth. It is therefore necessary to measure the signals by injecting known voltages or, as this method was not available on the first cruise, by making a crude adjustment based on the amplifier setting used on each series of observations. The method of measuring amplitude will be described later.

Noise may always be distinguished by its appearance on successive transmissions at roughly the same amplitude but never at the same position and usually over the length of

the time-base. This can be seen clearly in Figure 1 where the amplifier is turned well up. Compare this with later figures in which the amplifier setting has been chosen to reduce noise to a size at which it can only just be discerned on either side of a narrow piece of black paper (shown as a black mark in the figures) which covers the time-base.

CLASSIFICATION OF ECHOES

Echoes observed above the sea-bed may be separated into those completely free from the bottom echo and those lying close to the sea-bed.

1. ECHOES FULLY CLEAR OF THE BOTTOM SIGNAL

The simplest form of 'off the bottom' echo is that which extends vertically over a distance equivalent to the pulse length used. More usually the echo extends over two or three pulse lengths. In Figure 2, using a 10-fathom range, the apparent echo is about two pulse lengths, and below this is a further echo of about 4 pulse lengths; each of these two echoes is complete in itself. A similar type of echo is shown in Figure 3 which differs from Figure 2 in being taken on a 5-fathom range setting.

The simple type of echo builds up to the multiple type in which a number of echoes of varying amplitudes appear on the screen. Figure 4 is a good illustration of this, showing echoes of varying vertical extent and amplitude recorded on a 5-fathom screen range whilst the ship was lying stopped; the depth of water was 143 fathoms.

A further example of a multiple echo, Figure 5, taken in shallow water of less than 45 fathoms off the west of Hope Island in July, illustrates not only a multiple echo near the bottom but the criterion used to distinguish echoes given by fish from those caused by noise. In this illustration and in Figure 6 of a shoal in midwater, two consecutive soundings have been photographed on the same print. The same shape of echo can be seen on each exposure, although the amplitude of the echo has changed. In practice, a fish echo will build up over several transmissions (dependent on the distance of the shoal away from the ship, the ship's speed relative to the shoal and the path of the shoal through the sound-beam). Therefore, except when a shoal is located on the extreme edge of the beam, echoes from the same shoal will be recorded on more than one transmission. As this is usually the case, the slow build up and subsequent die away in amplitude of the echo is used as a criterion for distinguishing fish echoes from noise; the noise will occur on consecutive transmissions but will be positioned randomly on the screen and will not increase steadily in amplitude and then decrease (at approximately the same depth).

2. ECHOES LYING CLOSE TO THE SEA-BED

Certain echoes having many of the characteristics of true fish echoes appeared when the ship rolled. These echoes, which were called 'X' echoes, were always closely associated with the echo received from the sea-bed, extending as a very narrow echo, often of considerable amplitude, directly above and in contact over most of its length with the echo from the sea-bed. Two main characteristics distinguished these echoes from true fish echoes:—

(a) that they are extremely narrow and within the echo the individual cycles may be seen.
(b) that unlike a fish echo, which usually has the appearance of an inverted triangle (base uppermost, with sides sloping in), the X echo is, at its extremities (along its base), in contact with the sea-bed echo and is, in form, a triangle with its base on the sea-bed echo.

A further characteristic which is not unusual for X echoes, is that the edges of the echo are bright and clear, unlike those of the fish echo which are usually softer. When there is very severe rolling, the X echo might appear clear of the bottom in association with another echo on the sea-bed. Lastly, an X echo can usually be distinguished from a fish echo because the fish echo builds up slowly and then dies away slowly in amplitude over several soundings.

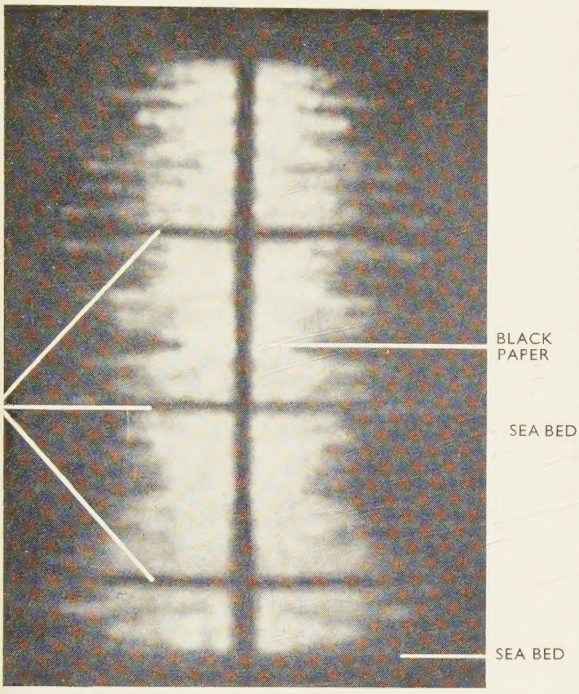


Fig. 1. *A photograph of the cathode ray tube of the echo sounder taken when the* ERNEST HOLT *was steaming at full speed in* 80 *fathoms of water. The amplifier setting is high, giving a high noise-level.*

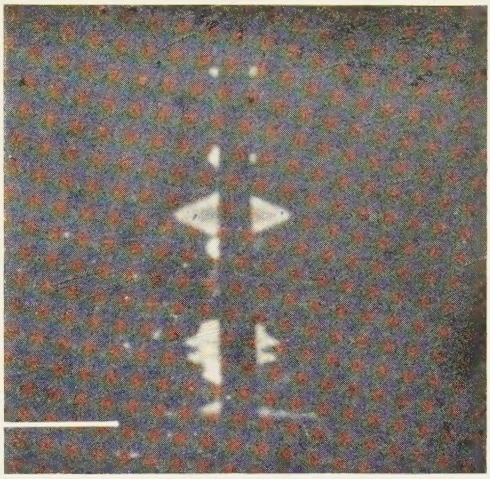


Fig. 2. *Two echoes, the upper about* 2 *fathoms off the sea-bed and the lower about* 1 *fathom off. These echoes were recorded with a* 10*-fathom range setting in* 135 *fathoms of water when steaming at full speed off Bear Island in June,* 1955.

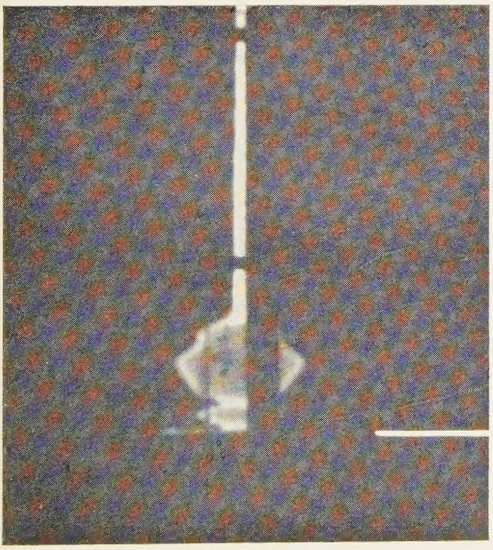


Fig. 3. *A similar type of echo to that shown in Fig.* 2 *but recorded with a range setting of* 5 *fathoms instead of* 10 *fathoms. In this case the echo is about a* $\frac{1}{2}$*-fathom off the sea-bed and was seen near Hope Island in July,* 1955.

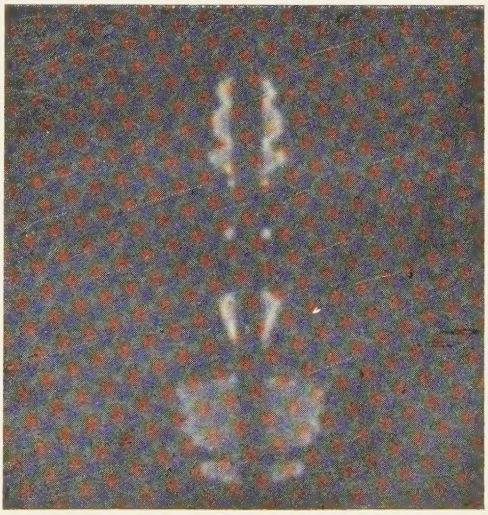


Fig. 4. *A multiple echo recorded on a* 5*-fathom range setting in* 143 *fathoms of water.*

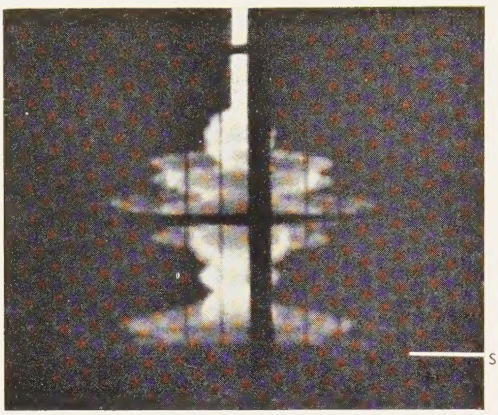


Fig. 5. *A multiple echo recorded in shallow water of* 45 *fathoms depth.*

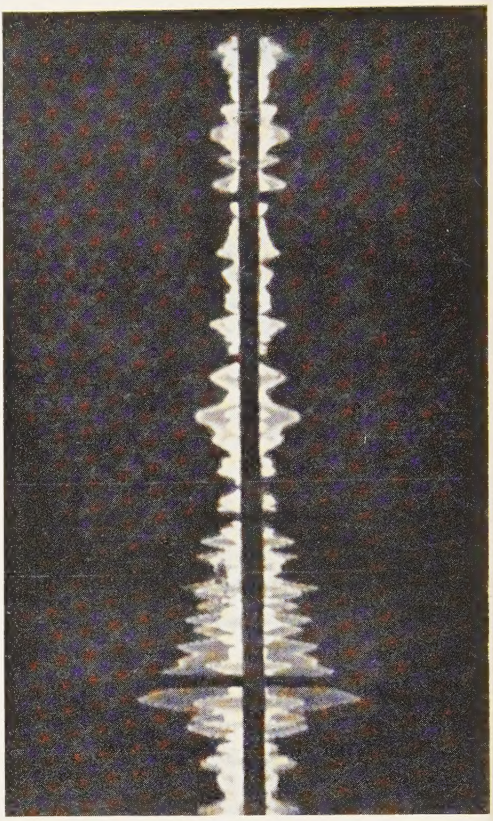


Fig. 6. *A midwater echo in which two transmissions have been recorded on the same exposure in order to show the consistency of fish echoes between soundings.*

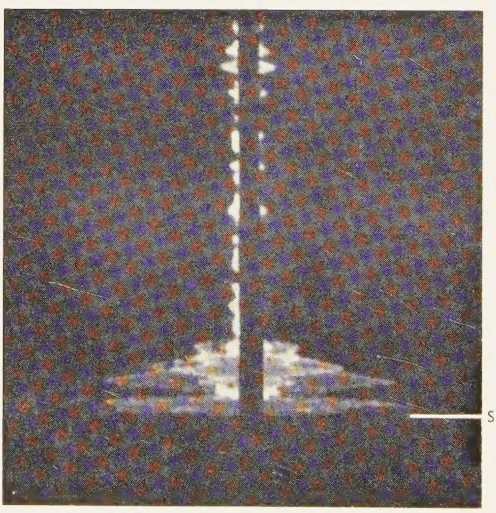


Fig. 7. *A typical 'X' echo in* 20 *fathoms of water.*

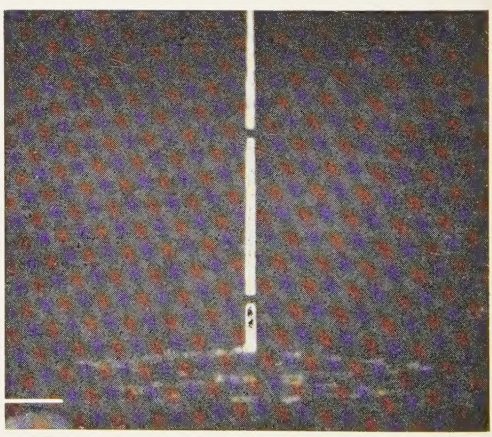


Fig. 8. *Two 'X' echoes produced by very rapid rolling of the ship.*

An X echo on the other hand, if it appears in two consecutive transmissions will change in amplitude rapidly and not follow a regular pattern of amplitude change.

The X echo is caused by the distance from the oscillator to the sea-bed being greater at the periphery of the sound cone than at the axis. Normally if the ship is steady, the echo from the axis of the beam, and this is the strongest echo, will be received first and the echo from the periphery of the cone, as it is received later, will be recorded slightly later in time. If the ship is rolling, the distance from oscillator to sea-bed may be shorter at one edge of the sound cone and this echo is therefore recorded before the stronger echo received from the axis. In this case, the smaller signal will appear slightly above the bottom echo and is then recorded as an X echo. Even though the X echo is weaker in relation to the axis bottom echo, it is still of greater amplitude than a fish echo.*

Figure 7 shows a typical X echo above which there is a fish echo. This was recorded whilst towing in 20 fathoms of water, and was on the 10-fathom range. Note that in this example where two consecutive soundings have been photographed, although there were records of the fish echo on both, the X echo was recorded only on one sounding.

An example of two X echoes appearing on the same sounding due to the extremely sharp roll of the ship producing an echo from the inward and the outward roll on the one sounding is shown in Figure 8. Here the hard edge, low intensity and outward slope of the top of the echoes can be seen.

METHOD OF MEASURING ECHOES

On the May–June 1955 cruise, before which we had no experience of either the form or distribution of echoes, it was necessary, apart from learning to distinguish the various types of echo, to evolve some method of evaluating the amount of echo observed during a tow. Although this method was made considerably more accurate in subsequent cruises, it was not basically changed.

A narrow strip of black paper $\frac{1}{8}''$ wide was placed down the centre of the screen over the time-base and the amplifier was adjusted to give noise just appearing from under this paper. The setting of the amplifier was noted and wherever possible, measurements were made at the same amplifier setting on all hauls within the area, thus making evaluation of the amount of echo between hauls easier.

The screen was also divided down the centre into five sections, each section equalling two fathoms on the 10-fathom range and one fathom on the 5-fathom range. In this manner it was possible to count echoes separately in whichever section they appeared and to obtain totals of echoes appearing between the bottom and 1 fathom off the bottom; between 1 and 2 fathoms off the bottom, etc.

A further division was made across the screen in order to separate the amplitude of the echoes into size-groups, i.e. up to the first mark, second mark, etc.

The system of counting the echoes was to have a series of stopwatches, one for each amplitude-group and one for measuring the amount of time the sounder was missing transmissions due to aeration. By this means, the total time-periods during which echoes of each size appeared on the screen, together with the total period when the sounder was missing transmissions, could be obtained for each haul.

ESTIMATION OF CATCH FROM ECHOES

In the early stages of this cruise, before any calibration graph could be worked out, a rough estimate of the number of baskets per tow was given in the wheelhouse before the trawl was on deck. The accuracy of these forecasts improved as the cruise proceeded, and showed that

*It has been suggested to us by Mr. M. J. Tucker that X echoes may be caused by signals from the side lobe striking the sea-bed more or less on the normal axis of transmission as the ship rolls.

a reasonable forecast of the catches could be made with very little experience of the echo sounder. During the cruise, the echoes were classified into three groups according to their amplitude. Some estimate of the quantity of fish represented by each record of echo at each amplitude could be made by solving the equations of time during which each-sized echo was recorded against the quantity of fish caught during the tow. The signal of smallest amplitude was equivalent to less than 0·01 of a basket for each second of appearance on the screen, whereas signals of the second amplitude represented slightly over one basket of fish for each second. Insufficient numbers of echoes of the third order were recorded to solve for this value. For all practical purposes, the smallest signals were not used in the calibration but only the number of seconds during which echoes of the second and third size were recorded and these have been plotted in Figure 9.

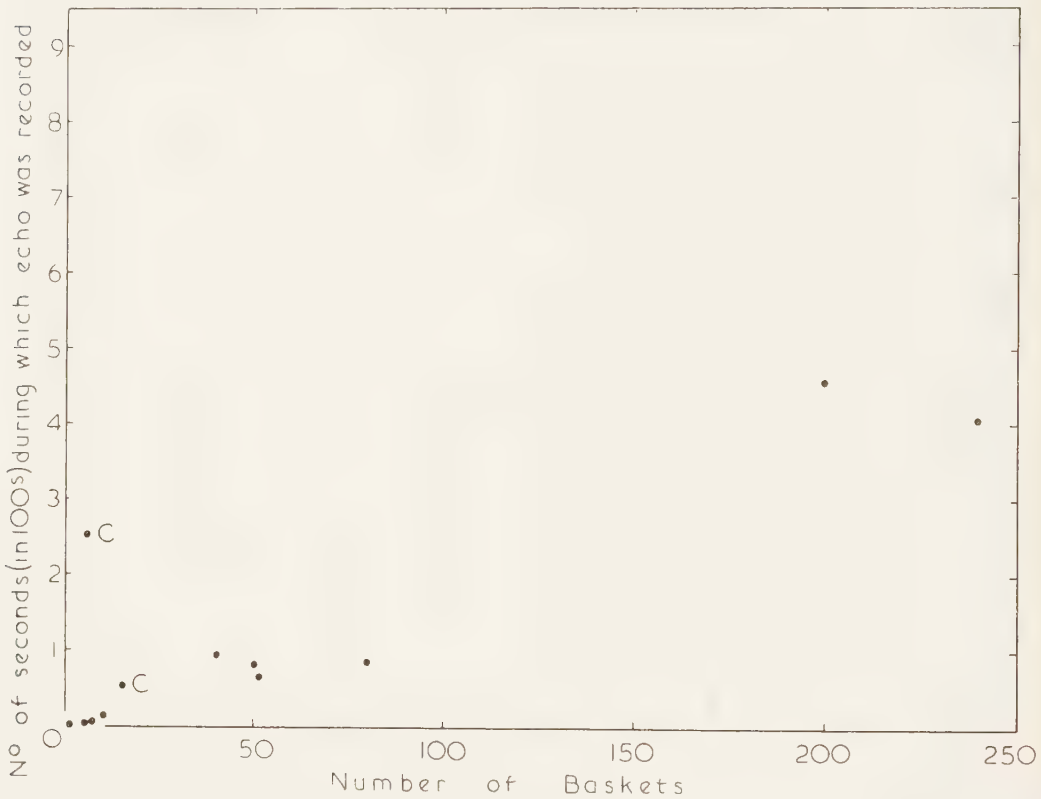


Fig. 9. *Relationship between the amount of time during which fish echoes were recorded and the catch of fish in baskets. On the two hauls marked 'C', a quantity of small codling were taken in addition to the larger fish.*

In this figure, the total number of seconds duration of echoes of the second and the third magnitude are plotted directly against the catch in baskets. No correction for depth, which varied from 100 to 130 fathoms, has been made because the range of depth was small but a correction has been applied for the amount of missing soundings due to aeration. No method of standardising the amplifier for variation was available on this trip; the results therefore incorporate any variations in the electrical system and in power output between hauls.

Two anomalous counts occurred (marked 'C' in Figure 9). It was noticed at the time of these hauls that the echoes were unlike those which had been recorded earlier in the cruise and that they were abundant over a great part of the haul, indicating that the catch should be large. However, the catch was much smaller than expected but the small-mesh cover on the trawl was full of codling too small to be retained by the codend mesh.

No distinction could be made between the echoes received from cod and haddock. Both species appeared to fit the calibration equally well on hauls in which there was mixing.

On a number of hauls, up to 5 baskets of catfish were caught but no echoes were recorded from these, possibly because, being fish without swim bladders and lying very close to the bottom, they did not give echoes which were measurable under the system used. During hauls, echoes were found to be localised; they occurred within a small part of the tow and very rarely were they distributed throughout the whole of the towing period. A negative relationship existed in that no echo during the haul coincided with no catch.

The results, as shown in Figure 9, indicate a linear relationship between the presence of echoes and the size of the catch, and allow the use of this method for forecasting catches. This being so, it follows that, providing water-noise does not become excessive, an echo-survey at full speed can be made using the above method of counting the echoes. This was in fact done in a small way on the first cruise but in more detail on later cruises. On the first survey, the localisation of echoes could be seen clearly: areas devoid of echoes gave no catch when fishing was carried out there, but catches were always made in areas where echoes were recorded.

Thus, from the first cruise, it is clear that (a) the catch can be forecast from measurements taken during a tow, (b) the localised distribution of the echoes during a haul means that fishing can be carried out with maximum efficiency because the trawl can be hauled as soon as echoes are no longer recorded and (c) an area can be surveyed to find the disposition of the fish before shooting the trawl.

SUMMARY

This paper gives an account of the method used in locating cod lying close to the sea-bed by means of an echo sounder with a cathode ray tube presentation.

A description of the appearance of fish echoes and the method of distinguishing them from (a) noise and (b) an echo, referred to as an X echo, which appeared frequently when the ship rolled, is included. By counting the number of transmissions in which fish echoes were observed when trawling in water of 100 to 130 fathoms depth, a linear relationship was obtained on this cruise between the echoes counted and the catch of cod.

II. ON THE RELATION BETWEEN TRAWL CATCHES AND COUNTS OF ECHO SIGNALS

by D. H. Cushing

INTRODUCTION

Fish echoes were recognized and recorded by the method described by Richardson. The three levels of amplitude in which the signals were classified were maintained by using a signal generator in series with the receiver. At the same time, measurements of water-noise were made; the signal-to-noise ratio was kept at a minimum of three to one.

During each trawl haul, signals from fish were measured by estimating their duration in seconds at each of the three levels of amplitude in the last fathom above the bottom signal on the CRT. It was assumed that the duration was proportional to the total signal measurable at the receiver between the given levels of amplitude; the duration in seconds for each of the three amplitude levels was multiplied by the appropriate mean amplitude. The three values of duration multiplied by mean amplitudes in micro-volts were added to give a total

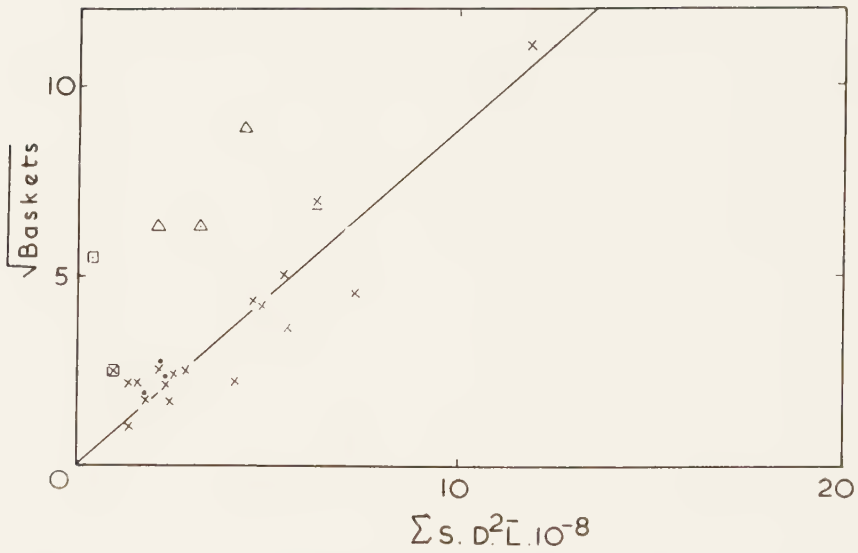


Fig. 10. *The observations made on Cruise V*, ERNEST HOLT, 1955. *Signals are corrected for differences in length of fish.*

X : normal observations.
Ẋ : observations made when the catch consisted largely of haddock.
[X] : observation made in shallow water under 40 fm.
△ : observations made when the ship's trim changed.
[·] : ditto but in shallow water under 40 fm.
X̲ : observation made after the forward tanks were filled with water.

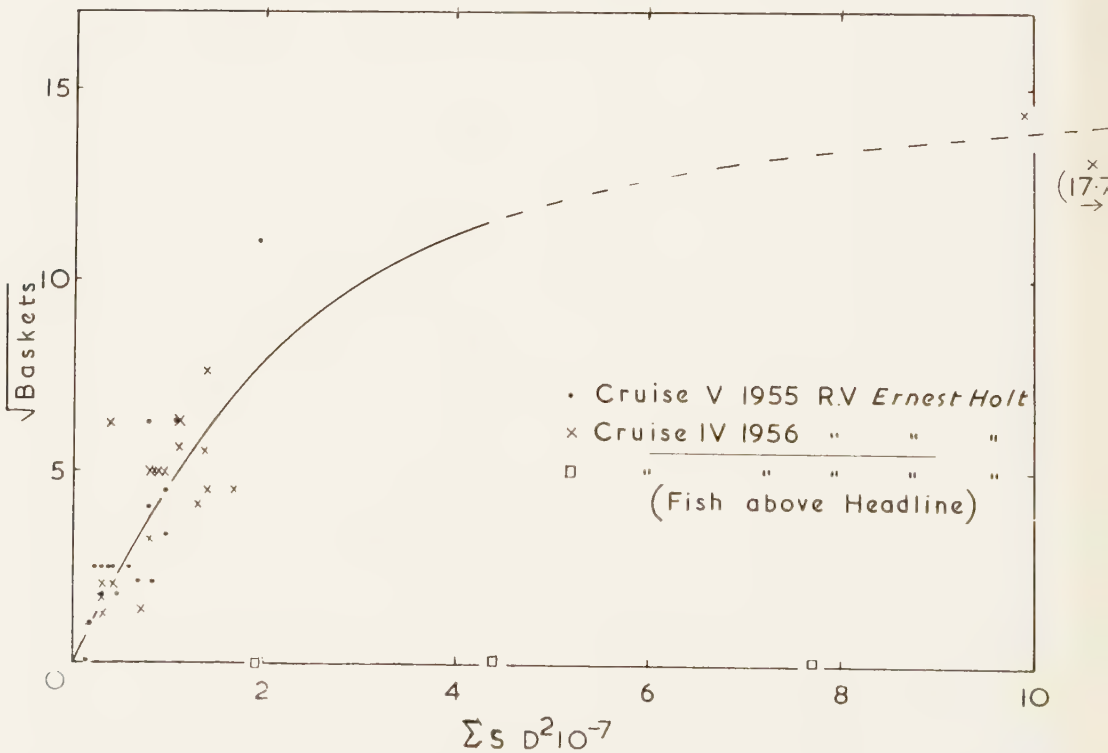


Fig. 11. *The relation between catch and signal obtained in* 1955 *and* 1956, *using all reliable observations for two cruises.*

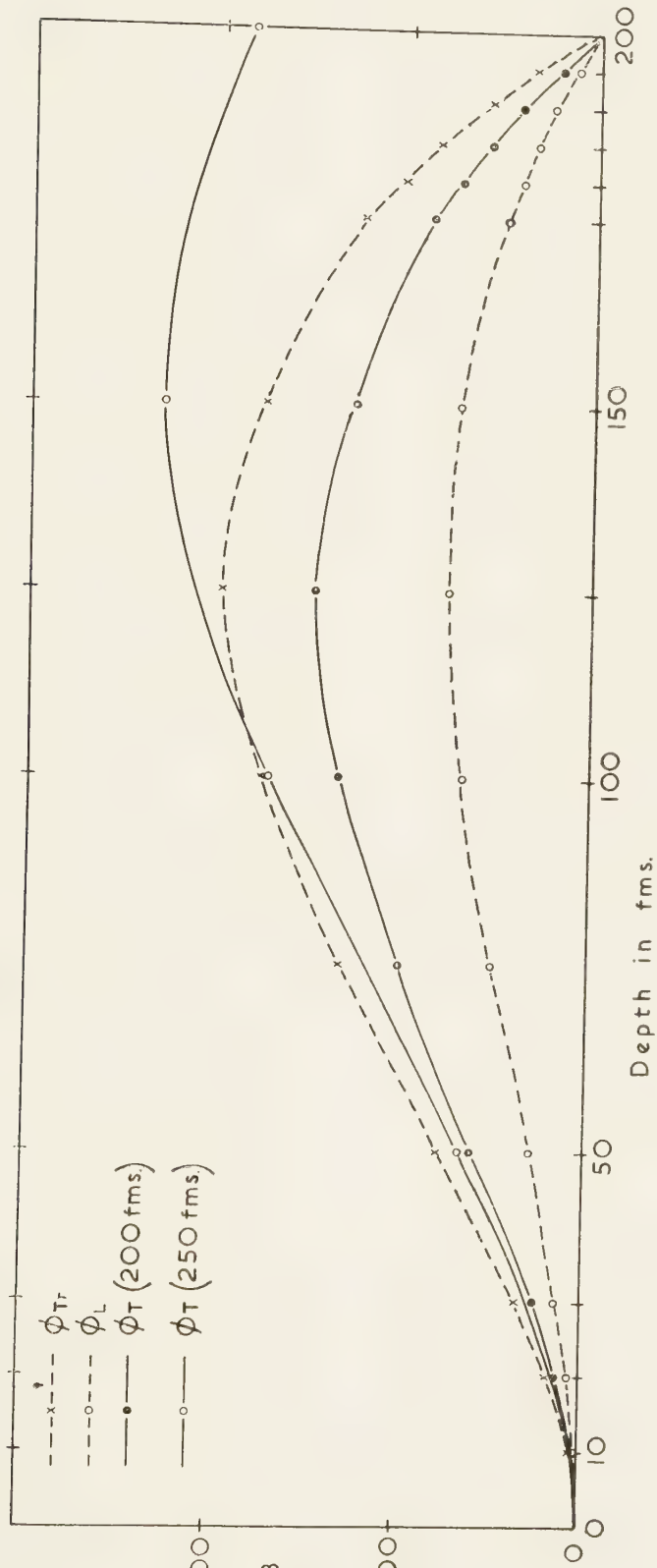


Fig. 12. *Polar diagrams estimated as the volume from which measurable signals are received*
Two targets are imagined which would be recorded on the axis only at 200 fm (—●—) and at 250 fm (—○—). The difference in transverse and longitudinal axes is shown by calculating the diagrams for each axis for the smaller target (– – – X – – –, transverse and – – – ○ – – –, longitudinal).

value $\sum S$, which was assumed to be an index of the total voltage measurable at the receiver during the trawl haul.

In Figures 10 and 11, the catch, expressed as the square root of the number of baskets of fish, has been plotted against $\sum S.D^2$, i.e. $\sum S$ multiplied by the square of the depth in fathoms. The reasons for the two corrections are as follows. The catch is an estimate of the numbers of fish in the volume of water scanned during the trawl haul, or roughly, the number of fish per unit area of sea-bed. The amplitude of a signal received from a shoal of fish is proportional to the square root of the number of fish; so the sum of amplitudes from a number of shoals of fish would be proportional to $\sqrt{n_1} + \sqrt{n_2} \ldots$ etc., where n_1 and n_2 etc. are the numbers of fish in each shoal. Thus, the square-root approximation assumes that the number of fish in each shoal is constant and that each shoal is collected, roughly as recorded. It is obvious from the signals shown in the first paper of this publication (Richardson) that most are longer than one pulse length and are therefore from shoals of fish and not from single fish. If all signals were received from single fish, then of course the square-root approximation would be unnecessary.

The basis of the depth correction is as follows. The energy reaching a small object (single fish or fish shoal) is reduced by the inverse square of the range of the object; the energy scattered back to the receiver by the small object is itself reduced by the inverse square of the range of the object. Consequently the intensity of a received echo is proportional to the fourth power of the range. Hence the received amplitude is inversely proportional to the square of the depth, or range.

Although the beam angle of the transducer was constant, the observations were in fact taken over a range of shoal sizes, including single fish, and over a range of depths, and so the polar diagrams of the targets were widely different.

Figure 12 shows two such polar diagrams, one for a small target and the other for a target somewhat larger. The method of calculation is given in Appendix I.

It will be noticed that the polar diagram for a given shoal size varies with depth, whereas it is obvious that the volume swept by the trawl is constant at all depths. Now the volume scanned by the echo sounder is a function of the constant beam angle and it increases with depth. Under conditions of constant shoal size, or numbers, the change in volume scanned with depth is countered by the change in received amplitude, because both are effects of the inverse square relation for received amplitude described above. So if received amplitude is corrected by the square of the depth, the volume scanned is inversely corrected; in other words, signals are reported as from a volume above unit area of sea-bed, which is the same as the volume swept by the trawl.

Hence the polar diagram as a basis for estimating the numbers of fish is unnecessarily complicated. Differences in shoal density, i.e. in the numbers of fish in each recognizable target, can be dealt with merely by changing the apparent beam angle.

RESULTS

The results are expressed in two figures: Figure 10 shows the observations for Cruise V, ERNEST HOLT, 1955, and Figure 11 shows all reliable observations for Cruise V, ERNEST HOLT, 1955 and Cruise IV, ERNEST HOLT, 1956, the depths of which varied between 50 and 175 fathoms. It was found generally that in less than 50 fathoms of water, the results obtained were not comparable, due, it is thought, to the difference in area scanned by the beam angle.

1. DIFFERENT SPECIES

Four species were observed in the catches; cod, coalfish, catfish and haddock. No difference was observed between signals from cod and haddock in their appearance on the tube and it was impossible in the catch-signal relationship to distinguish those stations at which haddock were or were not caught.

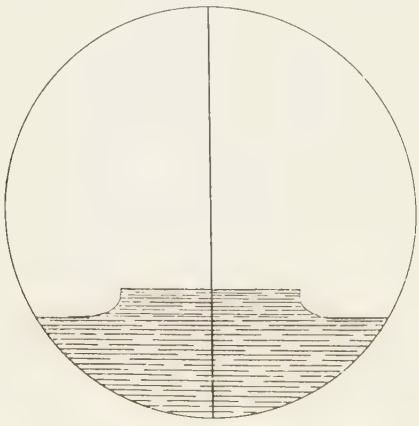


Fig. 13. *Diagram of signals which may have been received from catfish at station 78 on Cruise IV*, ERNEST HOLT, 1956.

At Station 78 on Cruise IV, ERNEST HOLT, 1956, four baskets of cod were caught and twenty-five baskets of catfish. There were a number of signals observed resembling X echoes which, however, did not appear as the ship rolled, and which were not photographed. These signals are illustrated diagrammatically in Figure 13; it is thought that they were received from catfish. Richardson (p. 7) noticed that no signal was received from catfish up to a catch of five baskets in depths of 100 to 130 fathoms; he attributed this to their lack of swimbladder.

In general, however, we were not able to distinguish signals as being received from different fish species.

2. THE SIZE OF FISH

The sizes of fish caught ranged from codling of about 25–30 cm to large cod and coalfish about 100 cm long; the mean length per haul varied between 40 and 87 cm. It is probable that signals from fish without their swimbladders are proportional to the horizontal cross-sectional area of the fish (Cushing and Richardson, 1955). Not only is the signal from a fish proportional to the horizontal cross-sectional area of the fish, but so also is the square of the length; hence, so long as the respective coefficients of proportionality are constant, signal is proportional to the square of the length. Catch is reported as the number of baskets, which is a measure of volume, proportional to the cube of the length. So, the correction for size of fish can be conveniently made by multiplying by the mean length. A comparison of the accuracy of the method using size correction with that using no correction is given in Table I.

Table I: *The effect of correcting for the size of fish*

	$\sum s.D^2.10^{-5}$	$\sum s.D^2.\bar{L}.10^{-8}$
r	0·9215	0·8985
slope	0·0531	0·8112
S.E. of slope	0·0056	0·0991
$\frac{\text{S.E. of slope}}{\text{slope}}$	0·105	0·122

The correlation coefficients given are between $\sqrt{baskets}$ and $\sum s.D^2.10^{-5}$ and $\sum s.D^2.\bar{L}.10^{-8}$ respectively, where $\bar{L}$ is the mean length; it will be seen that the standard error of the slope as a proportion of the slope is slightly increased when length is taken into

account, but the errors observed in the catch-signal relation cannot be related to differences in size as treated here, probably because the swimbladder has been neglected. Measurements by R. J. H. Beverton on Cruise V, ERNEST HOLT, 1955, gave the following values for this coefficient of proportionality (horizontal cross-sectional area/length squared):

Coalfish : 0·093
Cod : 0·078
Haddock : 0·078

Consequently, it appears that cod and haddock, considering their size alone, as distinct from any other specific difference, can be treated as the same. At three stations on this cruise haddock were caught in addition to cod and the mean length of fish caught was reduced, e.g. from 75 cm to 49 cm. A certain number of haddock in these hauls were caught in the codend cover and it was assumed that the numbers in these size ranges should be multiplied by five times to account for mesh selection. These observations at Stations 48, 50 and 67 (shown as X in Figure 10) are not significantly different from the other observations. Hence, for the purpose of forecasting the catch, it is probable that catches of cod and haddock can be treated as the same. (For survey purposes, however, it should be remembered that the two species are likely to be confused.)

3. THE EFFECT OF A CHANGE IN TRIM

Towards the end of Cruise V at stations 124–7, south of Bear Island, large catches were obtained with little signal in as much as 80 fathoms of water. The transmitted power cannot be checked with certainty, although some electrical conditions can be shown to be fulfilled. On this occasion the voltage into the inductive charger was correct, the contacts were at the right distance and the sparks were of the expected appearance. As a check, the receiver was remagnetized.

Whilst the hauls were being recorded, it was noticed that the number of echoes in a signal sequence had become reduced from six or seven to one or two. In other words, a fish echo no longer appeared at the bottom of the CRT and maintained its identity through half-a-dozen transmissions by climbing steadily up the time base and then steadily descending (which appears on the paper recorder as a 'comet' trace). Any fish echo appeared transitorily for one or two transmissions only and, therefore, became difficult to distinguish from noise. It was thought that this effect could take place if the oscillators were cocked up at an angle to the horizontal. Now the alteration in trim expected over the period of the voyage would amount to only 3° at the most; but at the same time, as she used her fuel and did not replace it with fish, the ship had become lighter and it is possible that the average angle made by the oscillators to the horizontal increased considerably when towing. The ship's weight and trim were partly restored by introducing 85 tons of water into the forward tanks. Three hauls were then made in the area south of the Island. Two effects were noticeable:—

(a) Fish echoes were again seen to maintain their identity through half-a-dozen transmissions.

(b) The prediction of catch from signal was again correct from 0 to 40 baskets per hour.

Consequently it is possible that the change in weight of the ship affected the behaviour of the echo sounders. Figure 10 shows the observations before (as triangles) and after (as an under-lined cross) adjusting for the change in trim.

4. THE POSSIBLE VERTICAL MIGRATION OF THE COD

At three stations on Cruise IV, ERNEST HOLT, 1956, no catch at all was made, but a considerable number of signals were received (shown in Figure 11 as squares). At these stations, signals of weak amplitude were observed in the fathom nearest the bottom, but signals of much greater amplitude were seen above them. This means probably that the fish were swimming more than one fathom off the bottom above the headline. Also at these stations, traces were recorded on the paper which extended as much as 40 fathoms from the bottom.

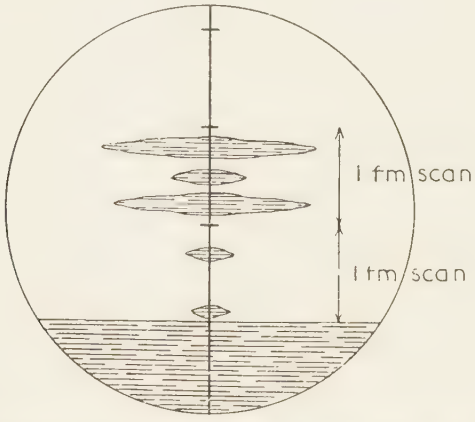


Fig. 14. *Diagram of the general type of echo received when fish are more than one fm from the bottom.*

At no other trawling stations were such traces seen. The type of CRT signal observed under this condition is shown diagrammatically in Figure 14.

It is possible that the same thing took place on Cruise V, ERNEST HOLT, 1955. On Stations 23 and 25, 3 and 8 baskets of coalfish were caught respectively; $\sum s.D^2.10^{-7}$ was 1·54 and 2·01 for the two hauls, which was four to five times too high. The coalfish were either exceedingly good reflectors or the majority were swimming above the headline; in view of the poor catches with strong signal associated with high swimming reported on Cruise IV, 1956 (and repeated on Cruise V, 1956), it is more likely that the coalfish were also swimming above the headline.

5. THE NOISE-LEVEL OF THE SYSTEM

In deep water, e.g. from 170 to 200 fathoms, signals from fish or fish shoals are weaker because of the greater range and are hence harder to distinguish from noise. Under routine survey or trawling conditions it is probable that some noise signals are recorded as fish, but it is unlikely that fish signals are discarded because they are interpreted as being due to noise. This is because fish signals are characterized by persistence through a number of transmissions.

During a count of five minutes duration, let 1 signal in every 30 secs. be recorded as from fish when it is actually of random origin. These random counts as $\sum s.D^2.10^{-5}$ are plotted against depth in Figure 15, from which the equivalent predicted catch at each depth can be calculated. In the extreme, there would be as much as 4 to 17 baskets of fish attributable to such random errors in counting at 200 fathoms; a similar count in 50 fathoms would amount to only one-tenth of a basket. The curve shown in Figure 15 could be said to show the 'noise-level' of the system, i.e. any predicted catch for a given depth would have to be at least two or three times greater than that estimated from the curve to be reliably differentiated from noise.

6. THE EFFECTIVENESS OF AMPLITUDE-MEASUREMENT

When fish echoes are counted on a presence or absence basis, the signal-to-noise ratio is high; the original echo-surveys, made with paper recorders, ran for days with the paper free from noise and the amplifier at a fixed setting. (Cushing, 1952). The consistent results obtained implied that the signal-to-noise ratio was maintained well enough despite possible variations in power output.

The counting of fish echoes at different amplitudes, however, means that a much lower signal-to-noise ratio has to be accepted on the lower amplitudes. As power variations would

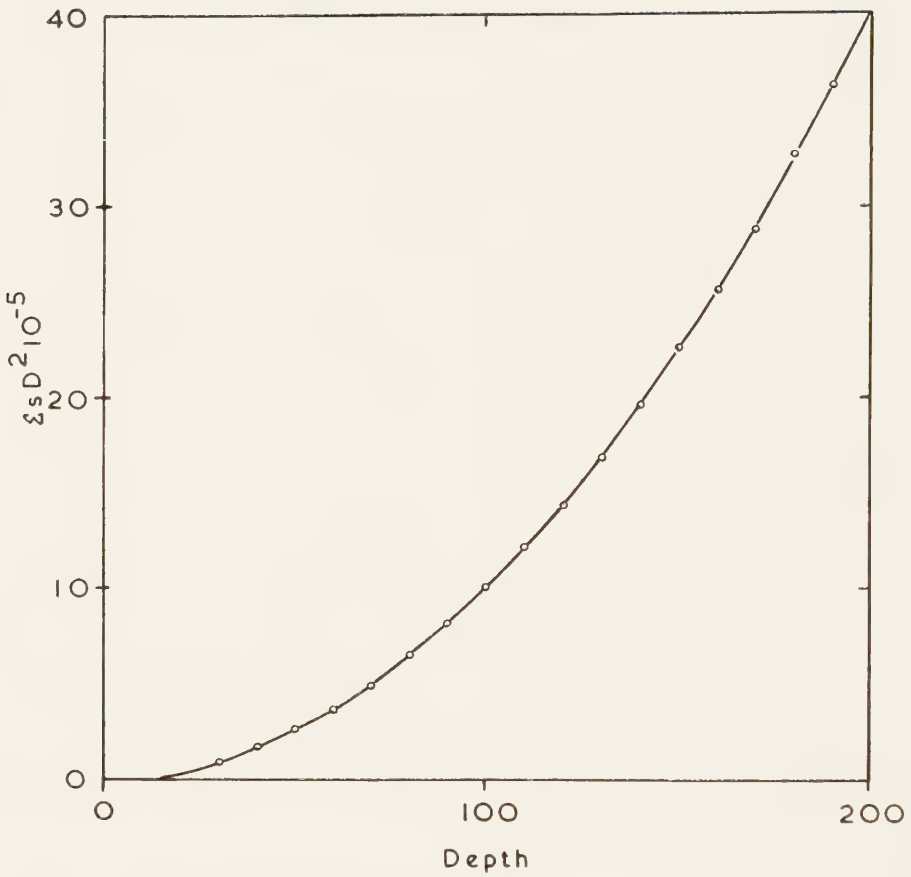


Fig. 15. *The noise-level of the counting system.*

alter the signal-to-noise ratio, it is possible that amplitude counting would be more variable and less effective than presence or absence counting.

The two methods of reporting the signals from fish are compared, the one counting the presence of fish signals in each transmission and the other measuring the amplitudes of fish signals in each transmission. Table II gives the errors in the relations, firstly, between catch as baskets and signal corrected by amplitudes and, secondly, between catch and signal uncorrected.

Table II: *Correlations between catch and signal corrected for amplitude and uncorrected*

	Corrected	*Uncorrected*
r	0·9215	0·8515
slope	0·0531	0·0574
S.E. of slope	0·0056	0·0088
$\frac{\text{S.E. of slope}}{\text{slope}}$	0·105	0·153

Thus, the effect of measuring amplitudes is to reduce the random error between the two variables, as shown by comparing the standard errors of the slopes, each as a fraction of the slope. Because amplitude measurement is also more sensitive at the higher levels of echo

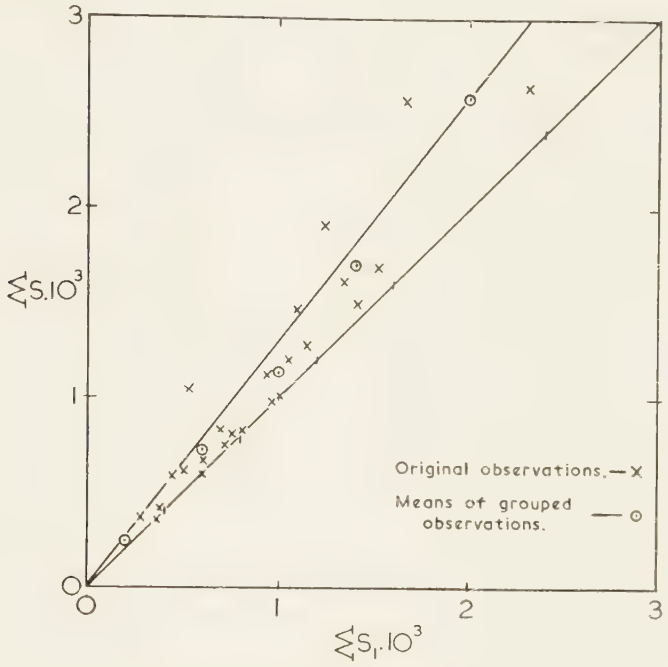


Fig. 16. *The effect of amplitude measurement.*

$\sum S$: total number of signals measured at and weighted by the three levels of amplitude plotted against $\sum S_1$: total number of signals measured.

density (see Figure 16), it would be desirable finally to use this method if the variability of power output and receiver sensitivity allowed it.

7. ADDITIONAL OBSERVATIONS

From Figure 11 it is seen that the observations from Cruise IV, 1956 fit in well with those of Cruise V, 1955. This in itself is remarkable when it is considered that there is nearly a year between the two sets of observations and that we had no means of checking the constancy of power output in the echo sounder used.

It will be noted that the relation between catch and signal is curvilinear, as if an asymptotic catch was being approached. At both levels of high catch the signals were underestimated both in number and in amplitude, but the signals in the bottom fathom were the strongest, so it is probable that the fish were not off the bottom. But those observations indicated as 'Fish above headline' all occur when the fish are abundant. Hence it is possible that the highest observations are underestimated in catch. On a linear relation such a signal would correspond to 1600 baskets per hour. As the signal was certainly underestimated and the maximum trawl catch recorded is probably about 400 baskets per hour, it is likely that the relation is really a curvilinear one. If this is so it is possible that this method could be used,

(a) to show that one should haul at the asymptotic level,
and (b) to study gear-saturation on trawls of different sizes and under different conditions.

DISCUSSION

From the results of two cruises in the ERNEST HOLT, it is shown that the relation between catch and counts of echo signal is valid between 50 and 175 fathoms in depth, that it can

be used with care down to 200 fathoms and that it is probably applicable with equal validity to cod and to haddock.

The error on the relation is such that one could probably contour an echo-survey using this method of counting at 1, 10, 50 and 150 baskets/hour. This is a much firmer basis than has been set up for any form of echo-survey so far employed.

APPENDIX I

METHOD OF CALCULATING THE POLAR DIAGRAMS SHOWN IN FIGURE 12

Let the maximum range (200 fm) at which signals of $m.\mu v$ are received from a unit target be R_T. Because this range is a maximum, it is also an axial range; at any lesser range, the signal received from the unit target is greater than or equal to $m.\mu v$ out to an extreme angle ϕ_T. Values of ϕ_T at different depths are obtained from the equation,

$$\frac{m}{q} = \frac{\sin\left(\frac{2\pi a}{\lambda} \cdot \sin\phi\right)}{\frac{2\pi a}{\lambda} \cdot \sin\phi}$$

where q is the signal received from unit target on the axis at any range less than R_T,
a is the width of the transducer in cm,
and λ is the wavelength of sound in cm.
Now the volume from which measurable signals are received (as distinct from the volume scanned, referred to on p. 10) is defined by,

$$\frac{2}{3}(R_2^3 - R_1^3)(1 - \cos\phi_T),$$

where R_2–R_1 is one fathom and R_2 is the depth.
This volume gives a measure of the polar diagram. The respective diagrams for each axis of the transducer (shown by broken lines in Figure 12), were calculated from the formulae given in the appendix to Beverton and Blacker's paper (Appendix II).

III. ECHO SOUNDING EXPERIMENTS WITH SINGLE COD

by
F. R. Harden Jones

INTRODUCTION

One step in the development of echo sounding as a quantitative method of estimating numbers of fish is to determine the strength of the signal returned by fish of different sizes at different depths on the axis of transmission, and to relate these measurements to the strength of water-noise at the frequency used. During Cruise VI of the ERNEST HOLT in

1955 measurements were made of water-noise and of the strength of the echoes returned by single dead cod.

METHODS

1. WATER-NOISE

Measurements of water-noise were made at 30 kc/s. with the sounder switched to 'free run', the transmitter then being off but the receiver open. What was judged to be the mean water-noise level observed on the cathode ray tube presentation of the scale expander was measured by comparison with a signal of known magnitude given by an Admiralty pattern signal injector placed in series between the output of the receiving oscillator and the first stage of the amplifier. Two series of observations were made, the first in one depth but the ship going at different speeds, the second at one speed but in different depths. The first series was made in 50 fathoms of water under good conditions, sea 1, swell 1, wind 0 (Beaufort scale), while data for the second series were collected throughout the cruise, none being taken in weather worse than sea 3, swell 2, wind 4.

2. EXPERIMENTS WITH SINGLE COD

These were carried out in excellent conditions, sea 0, swell 1, wind 0–1, over deep water off the west coast of Spitsbergen. There were two main series of experiments, both being carried out when the ship was lying. In the first series the fish were attached to sinkers and allowed to fall to the bottom, while in the second, the fish were tied to the wire of the plankton winch and lowered below the ship. The strength of the signal returned by a fish at different depths was measured by matching it on the scale expander with one of known magnitude from the signal injector. Preliminary experiments showed that the most consistent results were obtained by using fish in rigor mortis. In this condition, they neither became wrapped round the plankton wire nor appeared to sag under the pull of the sinkers. The fish were ungutted and probably contained some air from the swimbladder within the body-cavity. The significance of this is discussed later.

Series 1: *Cod attached to sinkers*

The fish were attached by nylon line, as shown in Figure 17(a), to a number of 500 gm concrete sinkers which hung 2–3 fathoms below them. Using 5–7 sinkers, the fish sank

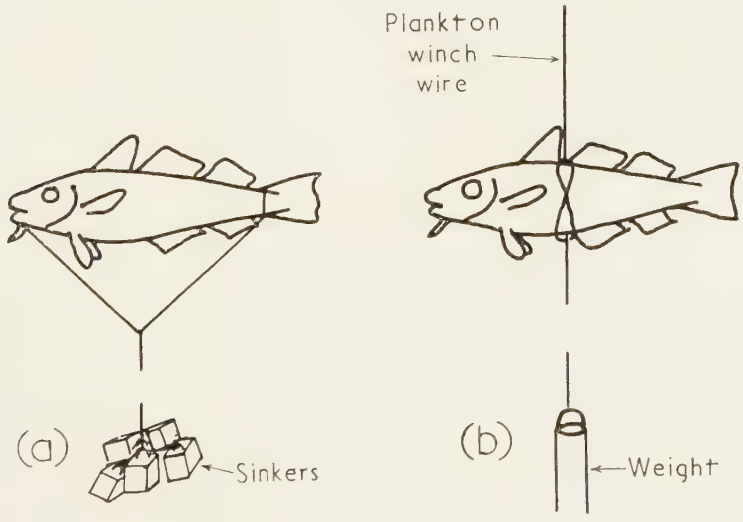


Fig. 17. *Dead cod attached* (*a*) *to concrete sinkers and* (*b*) *to the plankton wire.*

below the ship at about half a fathom a second. They always appeared to go down horizontally in their normal swimming position before being lost to view. Eight 80–90 cm cod were used in two sets of experiments in this series.

Series 2: Cod attached to the plankton wire

The fish were attached to the wire by trawl twine as shown in Figure 17(b). A heavy weight was shackled to the wire 2–3 fathoms below the fish. There was never any wire-angle visible at the surface when the wire was in the water. In these experiments four 80–90 cm cod were used, several others from a wide range of sizes and an 8-inch diameter steel trawl float as a control and standard target.

RESULTS

1. WATER-NOISE MEASUREMENTS

The results are shown in Figures 18 and 19. In Figure 18, it can be seen that the water-noise varies considerably at different speeds when over one depth and Figure 19 shows that at a given speed the 30 kc/s noise, which must be mainly due to propeller action, decreases rapidly and then more slowly, with the depth of water. During Cruise V, ERNEST HOLT, 1955, Cushing made further water-noise measurements under more variable weather conditions than those prevalent when the present series were carried out. His results, while showing a greater scatter, were similar to those figured here.

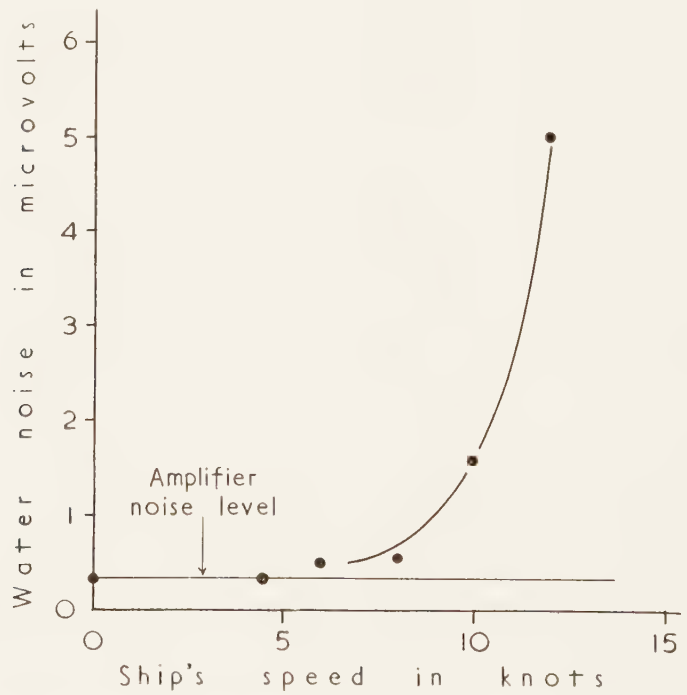


Fig. 18. *Relation between water-noise and speed of ship when in one depth* (50 *fm*).

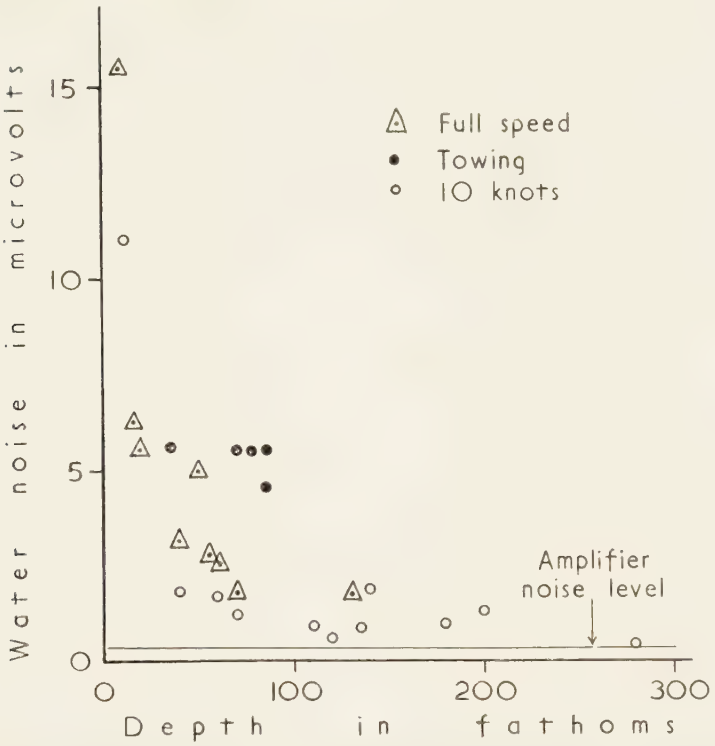


Fig. 19. *Relation between water-noise and depth at full speed, at 10 knots and when towing.*

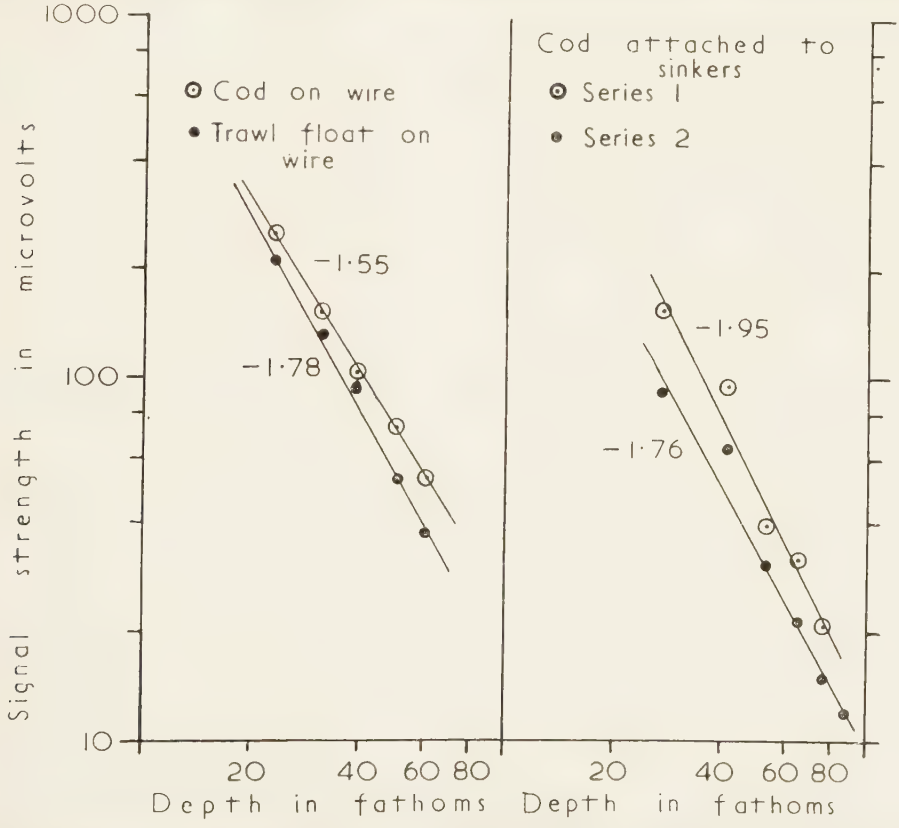


Fig. 20. *Log-log plots of signal strength at different depths for single dead cod and for the trawl float. For the cod, each point is the mean of four measurements.*

2. SIGNAL STRENGTH FROM SINGLE COD

The results for the 80–90 cm cod attached to the plankton wire and to sinkers are shown as a log-plot in Figure 20. If the amplitude of the echo received from a single fish varies inversely with the square of its depth, the slope of the regression of log signal strength against log depth should be — 2. The results obtained here with fish and a trawl float give values ranging from — 1·55 to — 1·95. The signal strengths obtained from cod of different sizes at one depth are shown in Figure 21.

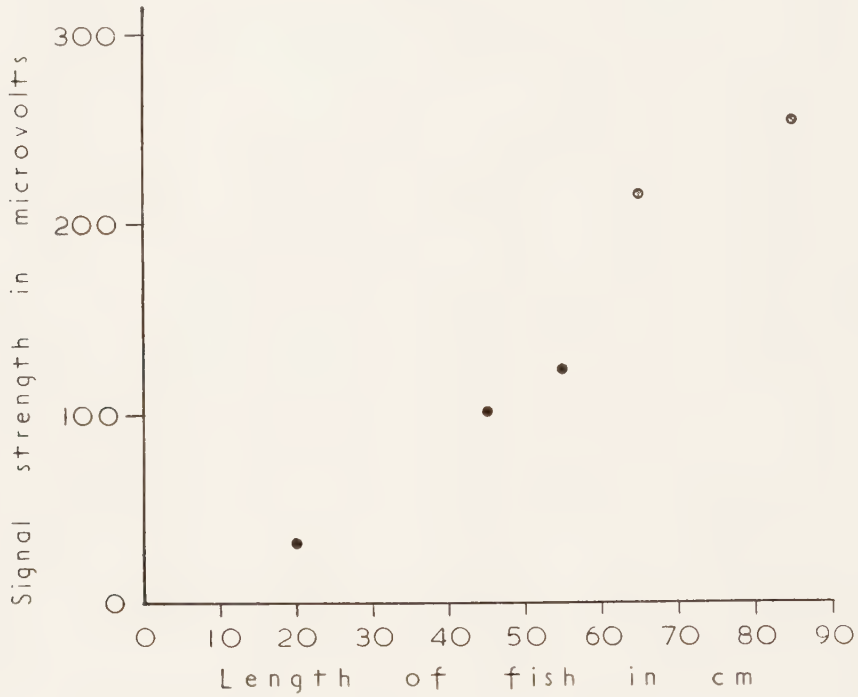


Fig. 21. *Signal strength returned by cod of different lengths.*

DISCUSSION

The experiments with single fish at different depths give results which show a slight departure from those expected according to the inverse square relation for amplitudes, in that the signal strengths were not decreasing with depth as rapidly as they should. The most likely explanation of this is that in both the plankton wire and sinker experiments, the fish enter the water-surface well off the axis of transmission but that this lateral displacement becomes proportionally less the deeper the fish is lowered or sinks below the ship. This would tend to produce the observed effect, so there is no reason to suppose that the apparent departure from the inverse square relation is other than a consequence of the methods used.

Taking the water-noise measurements and the strength of the signals returned by fish of different sizes, it is possible to give some idea of the signal expected to be returned by fish at different depths below the ship on the axis of transmission. This has been done in Figure 22. It will be seen that with the power output developed by the MS 24J on cruise VI/1955 and with the noise levels recorded at that time, and allowing for a workable signal-to-noise ratio of 3 to 1, it might be possible to detect a single 80–90 cm cod down to 170 fathoms when towing and down to about 300 fathoms when steaming at 10 knots. However it must be borne in mind that these are only rough estimates. Cushing and Richardson (1955) found in their Windermere experiments that the swimbladder alone returned from

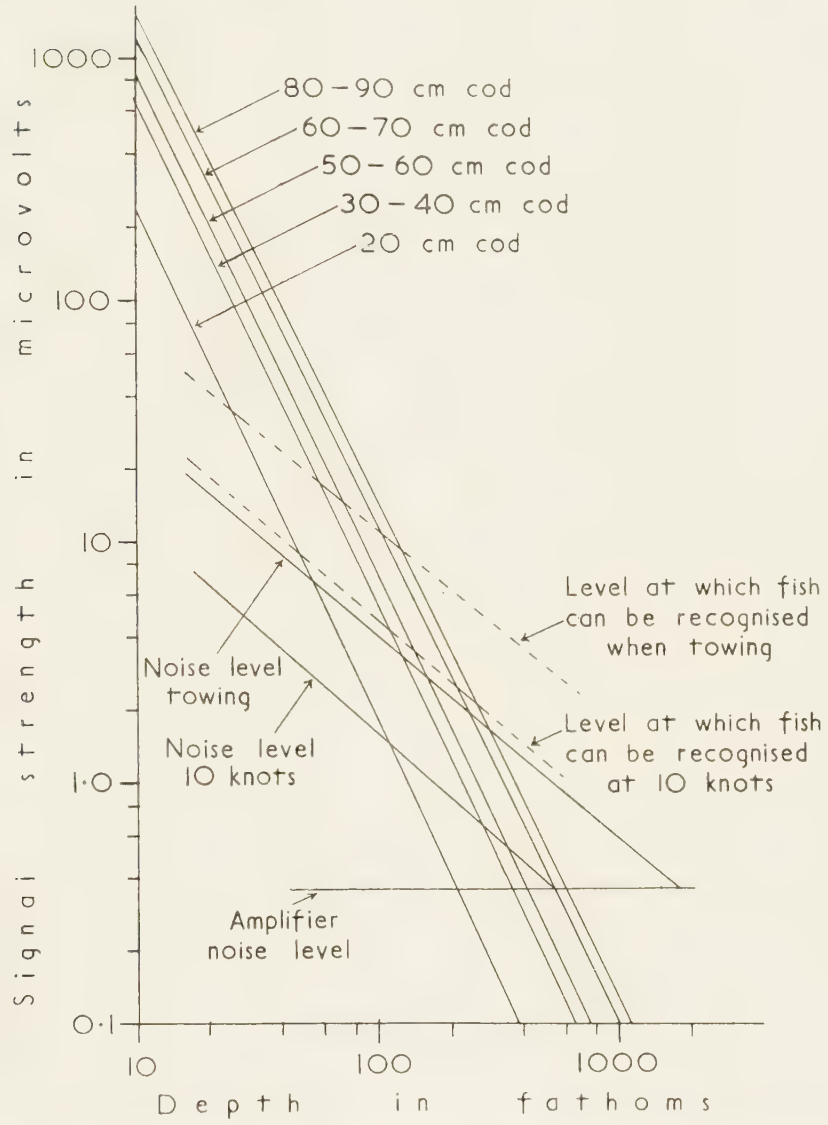


Fig. 22. *Signal strength expected from cod of different lengths at different depths in relation to water-noise when towing and when steaming at* 10 *knots.*

40 to 80% of the echo received from a fish and Jones and Pearce (1958) have confirmed this result in a series of measurements made under laboratory conditions. In the experiments carried out on the ERNEST HOLT, there can be no doubt that the fish used as targets, which had been caught in 40 to 70 fathoms and which were in rigor mortis when lowered below the ship, had very much less gas in their swimbladders than would living fish of similar size. The strength of the signal returned by them was therefore less than that which would be returned by living fish, which might perhaps be twice as much as that found in these experiments.

IV. EXPERIMENTS ON QUANTITATIVE ECHO SOUNDING IN DEEP WATER

by

R. J. H. Beverton and R. W. Blacker

INTRODUCTION

THE investigations described in this paper are a contribution towards the accurate measurement of fish density by echo-sounding techniques. The paper is in two sections. In the first, a method is described which enables the distribution of echo signal amplitude received from a standard target over a wide range of depths to be measured in various parts of the sound-cone and compared with the theoretical directivity pattern of the oscillator. In the second section, these results are compared with certain characteristics of the sound-cone of the same oscillator as deduced from signals received from single fish during echo-survey.

EXPERIMENTS WITH A TRAWL-FLOAT TARGET

1. METHOD

When attempting to make quantitative measurements at sea of the characteristics of an oscillator, one practical difficulty is that of determining the location, within the sound-cone, of the object being used as a standard target. This is especially so if it is wished that the observations should come from a wide range of depth such as might be encountered during survey for fish distribution (down to 120 fathoms in the present case). In these circumstances it is not satisfactory to suspend the target on a wire and attempt to deduce its location from the wire angle, because this would depend critically on the precise shape of the catenary taken up by the wire in the water, which would not be known.

The method described here depends on the fact that if an echo sounder is transmitting vertically downwards over a fairly level stretch of sea-bed, the bottom echo will be received at the true depth of the bottom immediately below the sounder. Furthermore, the echo from a target at a fixed height above the sea-bed will appear on the paper record or a cathode ray tube at the true distance above the bottom echo only if the target is also vertically below the oscillator. The range of a target from the oscillator when at any other point within the sound-cone will be greater than its depth, and its echo will either appear nearer to the bottom echo than its true height above the sea-bed, or be completely within the bottom echo and hence invisible. If the true height (h) of the target above the sea-bed (depth d) is known, and the apparent height (h') of its signal above the bottom echo on the CRT is measured, then the range of the target is $d - h'$ and the angle (ϕ) it subtends to the vertical axis of the sound-cone is

$$\cos \phi = \frac{d - h}{d - h'} \qquad (1)$$

These relations are illustrated in Figure 23(a), where the target is at B and the oscillator at O.

The practical details of the method are as follows. A heavy tubular weight (about 1 cwt; see W in Figure 23(a)) was attached to a thin hydrographic wire (4 mm diameter), and two or three 8″-diameter steel trawl floats were affixed to the wire at two-fathom intervals above the weight. The weight was slung horizontally to enable it to run smoothly over the sea-bed and to give a sharp echo which would not be confused with those of the floats. With the ship stopped, the procedure was first to lower the weight until it just touched the

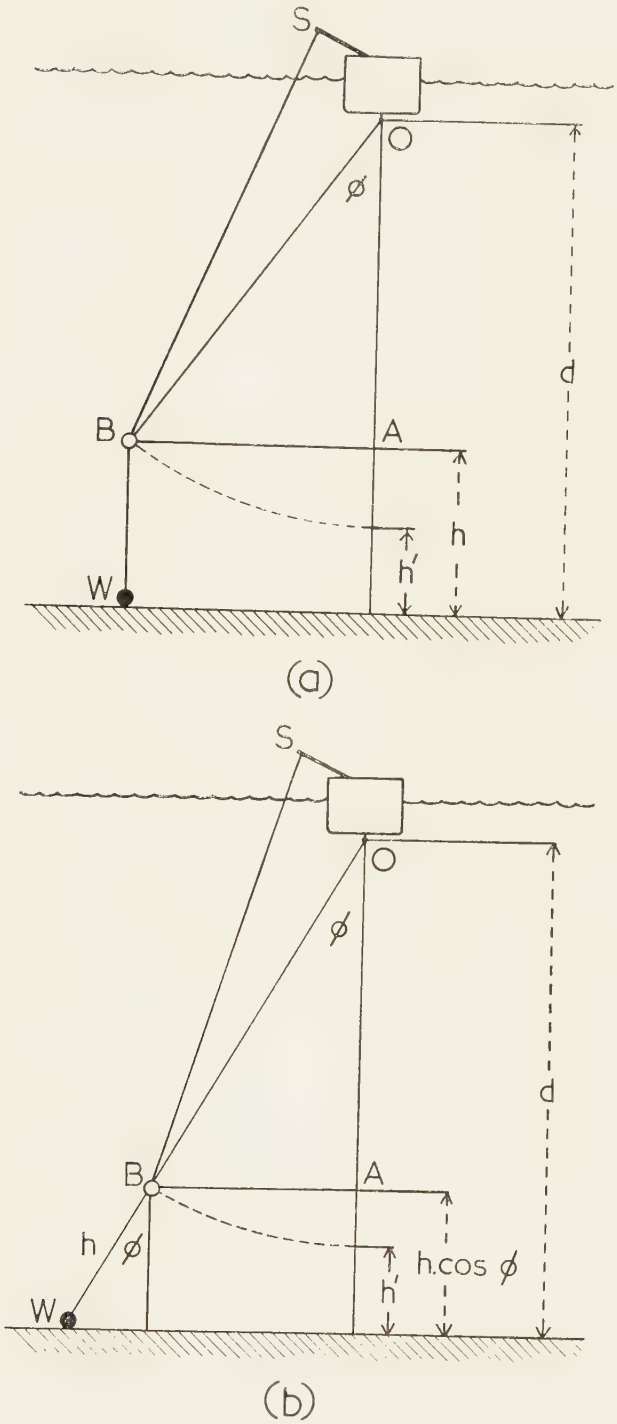


Fig. 23. *The theory of the trawl-float experiment.* O *is the oscillator,* B *the float,* W *the weight and* S *the point of suspension of the wire on the ship.*

(a) The simplest case, assuming the float B to be vertically above the weight W: then the actual height of B above the bottom equals h, the measured distance of the float from the weight, while the apparent height $\cos\phi = \frac{OA}{OB} = \frac{d-h}{d-h'}$ where ϕ is the angle subtended by the float to the vertical axis of the sound-cone.

(b) If the float is not vertically above the weight, it is less than distance h above the bottom. Assuming that the weight, float and oscillator are on the same straight line, the true height of B above the bottom is $h\cos\phi$, so that $\cos\phi = \frac{d-h\cos\phi}{d-h'} = \frac{d}{d+h-h'}$ which is the expression used in this paper for the estimates of ϕ.

bottom; this could readily be ascertained by watching the reaction of the accumulator spring on the davit. After a pause of a few minutes to allow the wire angle to become steady, with the drift of the ship dragging the weight over the sea-bed, measurements of the apparent height (h') of the signal from each float above the bottom echo, and of the amplitude (a) of each signal, were made on the CRT. When the first set of readings had been taken, a further half-metre or metre of wire was paid out and the ship allowed to drift until, again, a constant wire angle (larger than before) had been attained; a further set of readings of h' and a was then taken. This procedure was repeated until either the range of the topmost float had become greater than the depth of the bottom (so that its echo was lost in the bottom echo), or the amplitude of the received signal had become smaller than the minimum recordable signal.

If as thin a wire as possible is used, it may be that the buoyancy of the floats is sufficient to keep the wire nearly vertical in the region of the floats, in which case the distance along the wire of the float from the weight can be used as a direct estimate of its true height above the bottom (h). Alternatively, it can be assumed that the wire between the weight and the floats points towards the oscillator (Figure 23(b)), in which case the vertical height of the float above the sea-bed is not h but $h \cos \phi$, and instead of (1) we have:

$$\cos \phi = \frac{d - h \cos \phi}{d - h'}$$

from which

$$\cos \phi = \frac{d}{d + h - h'} \quad .. \quad .. \quad .. \quad .. \quad (2)$$

In the present series of observations, the estimate of ϕ obtained from equation (2) was usually about 5% smaller than that from (1).

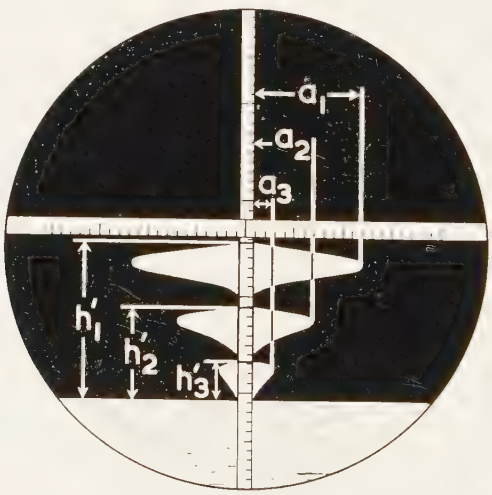


Fig. 24. *The cathode ray tube presentation.*

The vertical scale covers 5 fathoms, while the horizontal one measures amplitude on an arbitrary scale, calibrated for each sensitivity used. The three echoes show how the amplitude (a_1, a_2, a_3), and the corresponding apparent height of the float (h'_1, h'_2, h'_3) decrease as the float moves towards the edge of the sound-cone.

Figure 24 shows the appearance on the CRT of the echoes from a single-float target subtending three successive angles to the vertical axis. The corresponding amplitudes (a_1, a_2, a_3) and heights of signal above bottom (h_1', h_2', h_3') both decrease as the target is moved nearer to the edge of the sound-cone by paying out more wire. This diagram also shows the vertical and horizontal scales fitted to the face of the CRT from which values

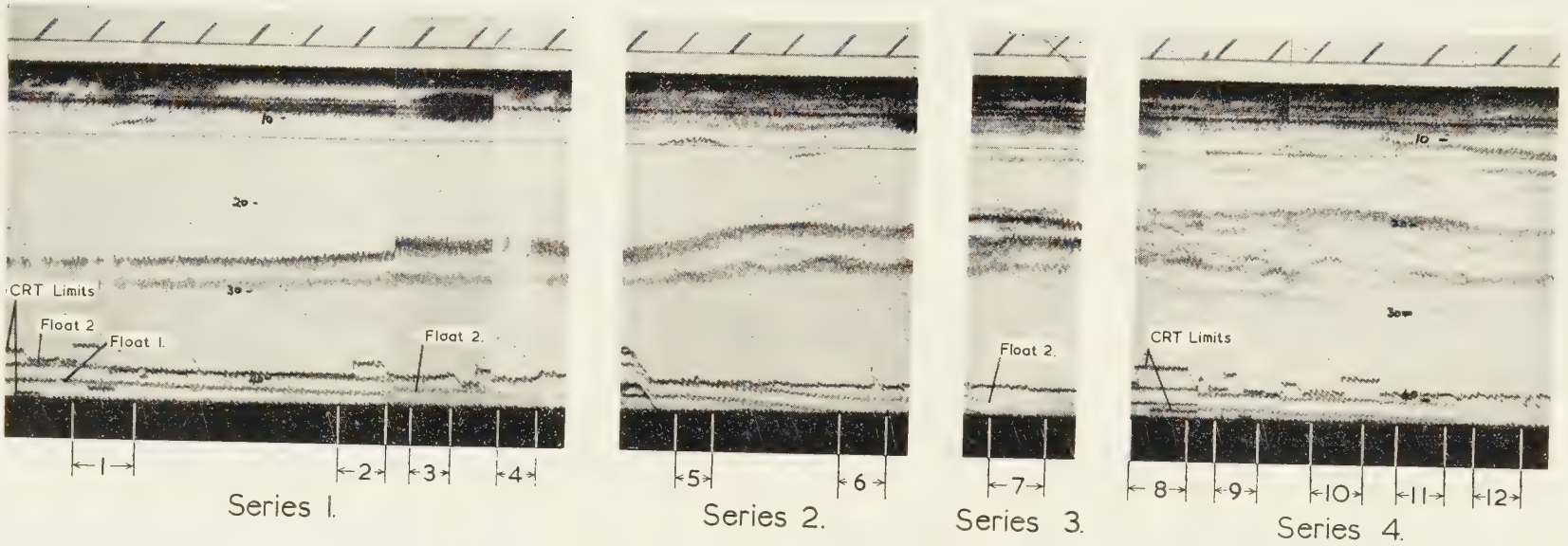


Fig. 25. *The echo-paper record of a typical series of observations.*

This is the record of Station 182 in 40 fathoms, showing four series of measurements, using two floats only. At 3, float 1 is just visible at the bottom; at 4, 7 and 12 its echo is lost in the bottom echo, while that of float 2 is near the minimum recordable signal level.

of h' and a were read off. The horizontal amplitude scale was calibrated by means of a signal injector so that signal amplitude could be expressed in micro-volts. Owing to the roll of the ship, the average amplitude over a period of about 15 seconds was taken, and h' measured when the ship was at the middle of the roll. Although the primary measurements were made on the CRT in this way, the paper recorder was always run while lowerings were in progress and provided a useful check on the values of h'. Figure 25 is the paper record of a typical series of observations, in which the signals from the floats can be seen to approach closer to the bottom echo as more wire is paid out.

Since the directivity pattern of a rectangular bar oscillator (as used in these experiments) is not radially symmetrical, it is necessary to know also the direction of the vertical plane containing the angle ϕ subtended by the target-float. Provided, however, that the long and short axes of the oscillator are not too dissimilar (e.g. their ratios are not greater than about 2 : 1) this direction is not critical and in practice can be determined with sufficient accuracy by measuring the direction in which the wire is leading relative to the ship's head.

Two essentials for the successful application of this method are a calm sea and a smooth, level sea-bed. If the roll of the ship is too pronounced, the amplitude of the received signals varies over too wide a range to enable accurate measurements to be obtained; while if the sea-bed is not level, the weight may not be continuously in contact with it, thus introducing an error in the true height h of the target-floats above the bottom, which can have a marked effect on the estimate of the angle subtended by the target. A slight breeze or current is needed to cause the wire to lead in a definite direction throughout a series of lowerings.

Despite what may seem to be the rather exacting nature of these requirements, a spell of good weather may provide a number of opportunities for its successful application. The present experiments were conducted on convenient occasions over a period of two weeks during a cruise of the ERNEST HOLT in the western Barents Sea in July–August, 1956, and only one out of nine stations had to be abandoned (on this occasion, the complete absence of wind and current prevented the ship from taking up any definite drift). The echo sounder used was a Kelvin Hughes Kingfisher with a CRT scale expander. The trawl floats used as targets were Phillips Patent 8″-diameter steel deep-sea models.

2. RESULTS

The full data and computations for one station are given as an example in Table III. The estimates of ϕ given in column D were obtained from equation (2) which allows for the inclination of the wire, but all subsequent calculations have also been carried through with estimates of ϕ derived from equation (1), with no substantially different results. Since at the shallower stations, the distance between the floats would itself have introduced an appreciable difference in the signal amplitudes recorded, each set of signals from floats 1 and 3 has been adjusted according to the inverse square law, to refer to the same range as that of float 2, which is the top float when two are used or the middle when three are used. The resultant figures are given in column E of Table III.

The relation between subtended angle and amplitude at each depth worked is shown in Figure 26 (a)-(h). It is sufficient for the present purposes to represent the trends by linear regressions, since the slight curvature that is present in the theoretical directivity curves for these conditions over the range of ϕ covered by the data (8° to 25°)* is too small to be detected, as is discussed further below. Near the axis of the sound-cone, however, the true curve bends over appreciably, and the regressions are discontinued over this range. The level of the minimum recordable signal was about 4 μ-volts, which is shown in the diagrams by a horizontal broken line. The general precision of the data is clearly sufficient to establish the regressions with reasonable accuracy from relatively few measurements, and it is possible to take the analysis further.

Within the restriction of a linear interpretation of the theoretical directivity curves, the characteristics of the sound-cone can be defined sufficiently well for present purposes in

*Few values of ϕ less than 10° were obtained, since the wire invariably took up some angle as soon as the weight touched the bottom. At most stations, the echoes received from floats subtending angles much greater than 20° were too weak to measure.

Table III: *Trawl-float experiments: Data of echo amplitude from a trawl-float target at various positions in the sound-cone at a depth of* 97 *fathoms* (*Station* 194, *see Fig.* 26(*g*))

Float No.	*A* *Corrected total depth (d) fm*	*B* *Distance of float from weight (h) fm*	*C* *Apparent height of float above bottom (h′) fm*	*D* *Estimated angle subtended by float (φ)*	*E* *Amplitude of echo signal (μv)*
1	101	2·4	1·3	8·4	11
1		2·4	0·4	11·3	11
1		2·4	0·1	12·1	6·6
2		4·4	3·3	8·4	13
2		4·4	2·5	11·0	11
2		4·4	1·9	12·6	8·5
2		4·4	1·6	13·3	8·5
2		4·4	0·0	16·6	6·3
3		6·9	6·0	7·6	10
3		6·9	5·1	10·7	10
3		6·9	4·6	12·1	10
3		6·9	4·3	12·9	10
3		6·9	2·5	16·6	8·1
3		6·9	2·1	17·3	6
3		6·9	1·5	18·3	6
3		6·9	1·5	18·3	4·4

terms of two features, (a) the 'extinction' angle, i.e. the angle at which the regressions of Figure 26 cut the x-axis, and (b) the general relation between signal strength and depth. The first of these is, in effect, a measure of the beam angle of the oscillator; it should be independent of depth but owing to the shape of the oscillator it should vary according to the vertical plane in which the regression is measured. The change of signal amplitude with depth would be expected to follow the inverse square law, provided there is no appreciable attenuation or distortion due to non-uniform acoustic properties of the medium. As a convenient index of the level of signal amplitude at each depth, the amplitude at a subtended angle of 15° (estimated from the regressions of Figure 26) was chosen, since this angle was near the middle of the observed range of ϕ at all stations*.

The estimated extinction angles at each depth are given in Column G of Table IV, and are calculated from the least squares regression coefficients of columns D and E. In this table the stations are arranged according to the direction, relative to the ship's head, of the lead of the wire from which the target floats were suspended, which corresponds roughly to the direction (ψ) of the vertical plane containing the subtended angle ϕ. This distinction is necessary from now onwards, since the departure of the shape of the sound-cone from radial symmetry causes not only the extinction angle but also the 15° amplitude to vary according to the plane in which it is measured.

*The estimated amplitude at zero angle would have been a better index had all the regressions been generated by a target moving radially, since in such a case it would have been a constant ratio of the true axial amplitude and the same for all radii. In practice, it was necessary to suspend the target from a point some little way from the oscillator; this caused the track of the target to depart appreciably from the radial, so that these advantages did not apply.

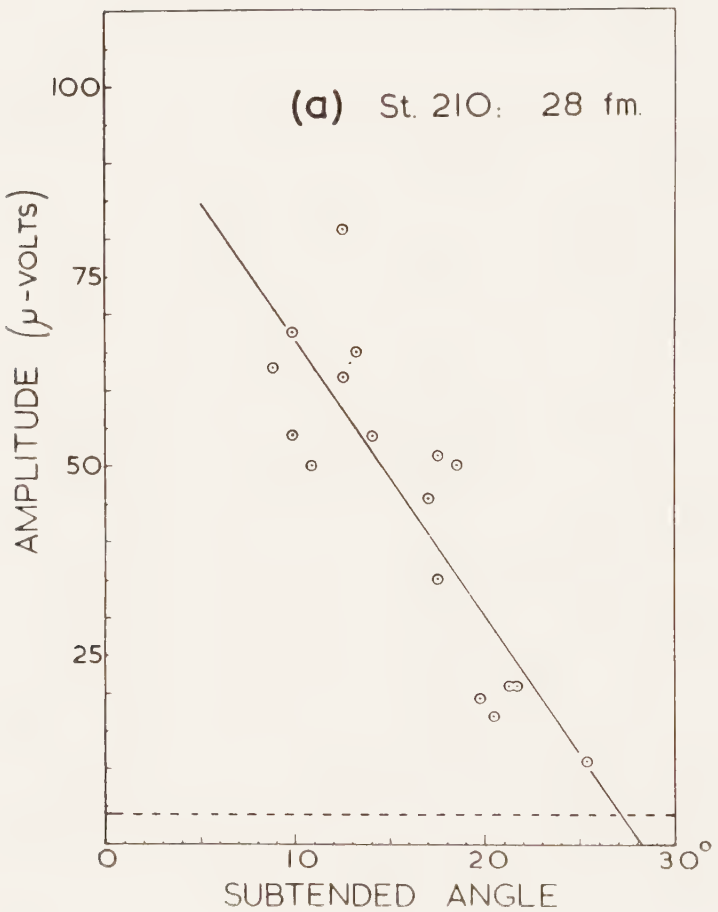
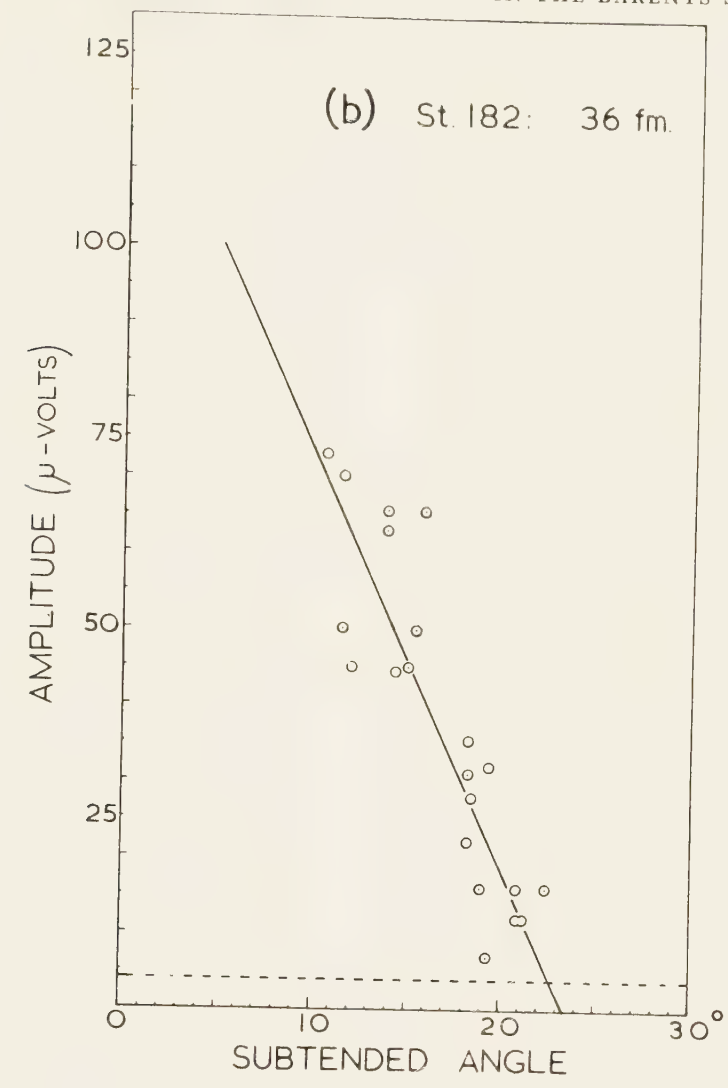
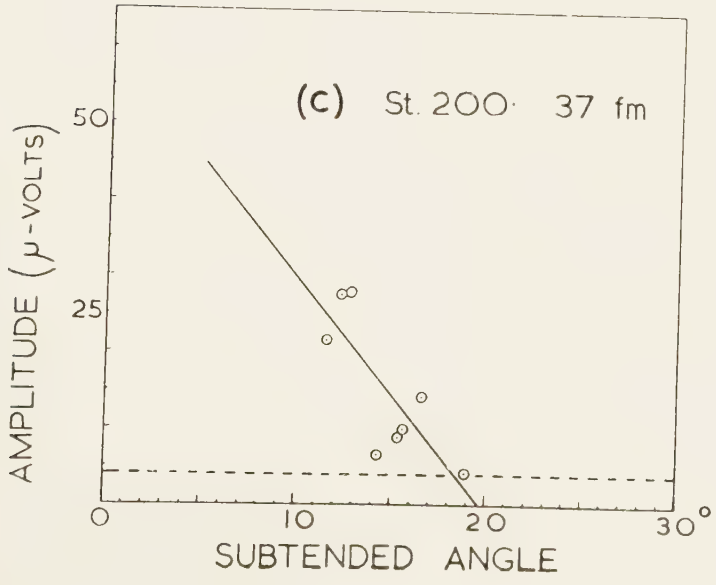
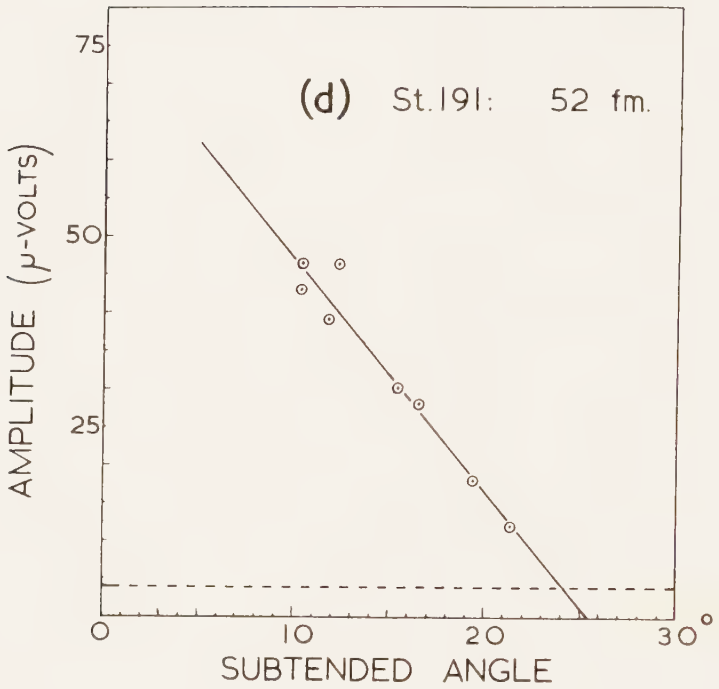


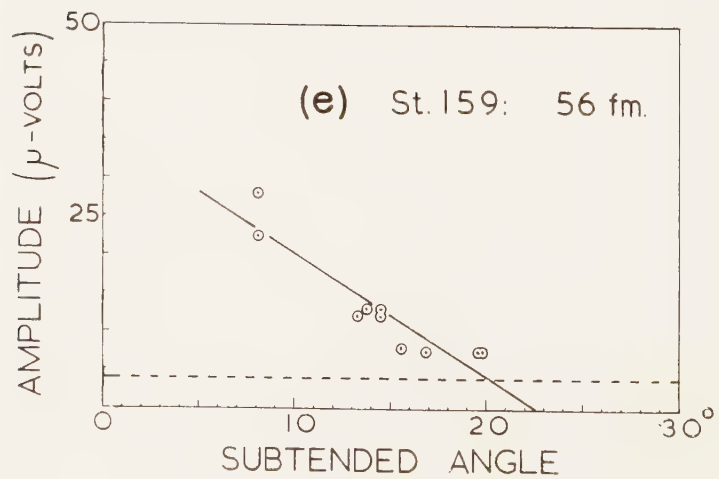
Fig. 26(a-h). *Regressions of amplitude on subtended angle at each station.*

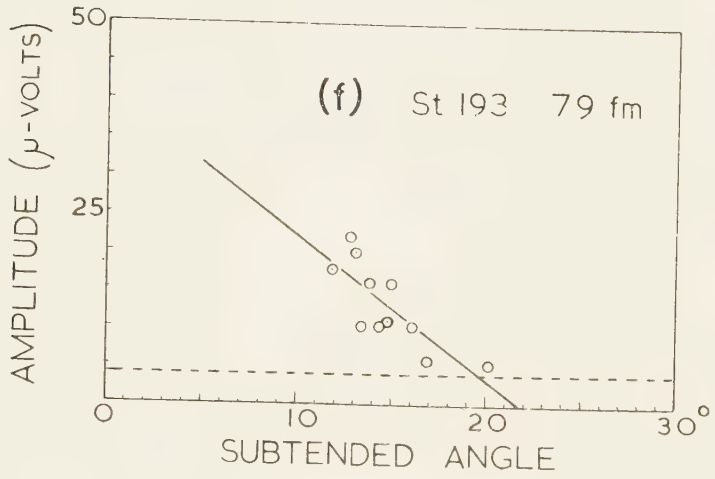
The minimum recordable signal level is shown on each graph by the dotted line. The linear regression is not continued between 0° and 5° because there the theoretical directivity pattern is appreciably curved (see Fig. 27a). The regression coefficients, estimated 15° amplitudes and extinction angles for each station are summarised in Table IV.

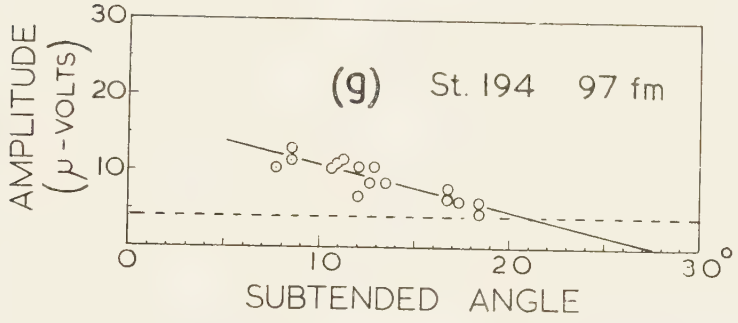

(b) St. 182: 36 fm.
125
100
75
50
25
AMPLITUDE (μ-VOLTS)
0
10
20
30°
SUBTENDED ANGLE


(c) St. 200· 37 fm
50
25
AMPLITUDE (μ-VOLTS)
0
10
20
30°
SUBTENDED ANGLE


(d) St.191: 52 fm.
AMPLITUDE (μ-VOLTS)
75
50
25
0
10
20
30°
SUBTENDED ANGLE


(e) St.159: 56 fm.
AMPLITUDE (μ-VOLTS)
50
25
0
10
20
30°
SUBTENDED ANGLE


50
25
AMPLITUDE (μ-VOLTS)
(f) St 193 79 fm
0
10
20
30°
SUBTENDED ANGLE


30
20
10
AMPLITUDE (μ-VOLTS)
(g) St. 194 97 fm
0
10
20
30°
SUBTENDED ANGLE

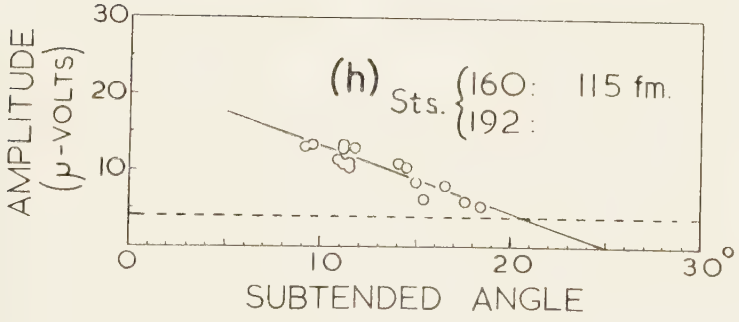

30
20
10
AMPLITUDE (μ-VOLTS)
(h) Sts. {160: 115 fm.
192:
0
10
20
30°
SUBTENDED ANGLE

Table IV: *Trawl-float experiments: Summary of regression coefficients, 15° amplitudes and extinction angles (see Figures 26)*

A	*B*	*C*	*D*	*E*	*F*	*G*	*H*
Station	*Depth (fm)*	*Direction of wire*	*Regression coefficients*		*15° Amplitude*	*Observed Extinction Angle*	*Theoretical Extinction Angle*
			a_0	a_1			
182	36	Abeam	126·2	− 5·333	46·2	23·7	24·3
191	52	Abeam	76·5	− 2·989	31·7	25·6	24·3
193	79	Abeam	41·0	− 1·894	12·6	21·6	24·3
194	97	Abeam	16·3	− 0·579	7·6	28·1	24·3
160, 192	115	Abeam	21·4	− 0·853	8·7	25·1	24·3
200	37	Aft	63·7	− 3·272	14·6	19·5	18·7
159	56	Aft	36·0	− 1·585	12·2	22·7	18·1
210	28	45 forward	104·0	− 3·644	49·3	28·5	23·7

The dimensions of the oscillator were such that the area insonified at a given depth was elliptical, with the major axis running athwartships and roughly $1\frac{1}{2}$ times the length of the minor axis.

At the first five stations listed in Table IV the wire led directly abeam, but because the point of suspension of the wire was behind and to one side of the oscillator, the target-float did not travel strictly along the major axis of the oscillator. However, calculation of the theoretical directivity curve for the actual track of the target-float showed that over the

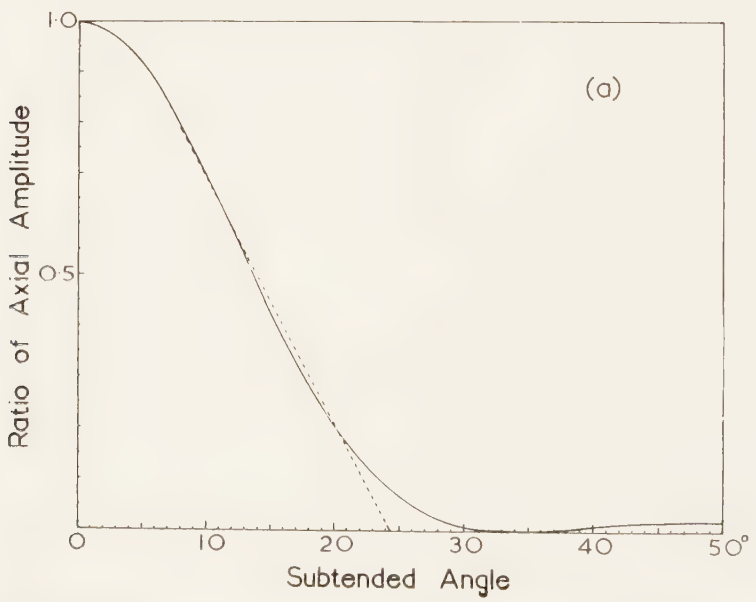


Fig. 27(a). *Theoretical directivity curve (full line) for a bar oscillator (14·5 cm × 9 cm) mounted with its long axis running fore and aft.*

Transverse axis (major axis of the insonified area). A linear regression over the range of observed angles is shown by the broken line.

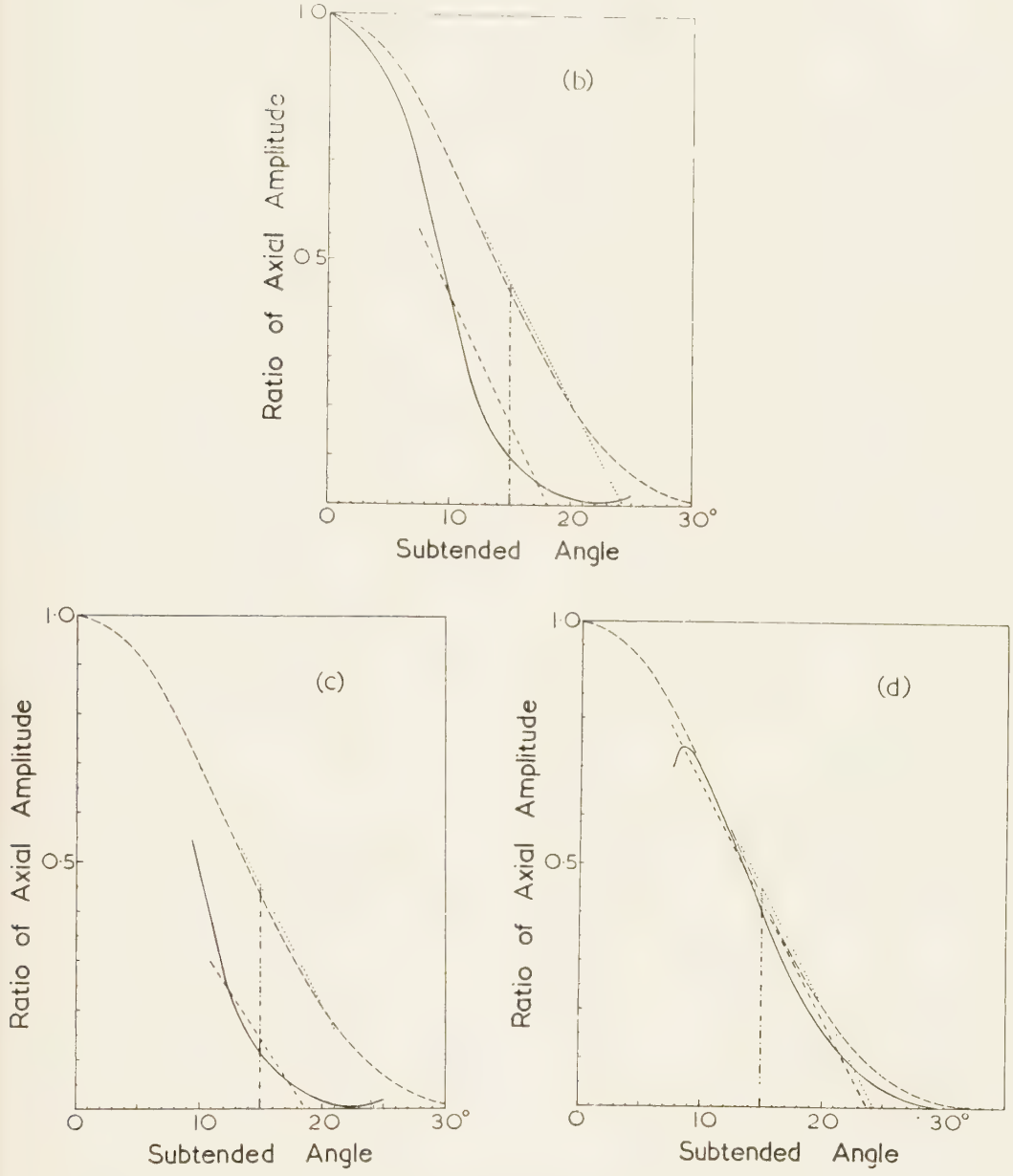


Fig. 27(b)–(d). *Theoretical directivity curves (full lines) for a bar oscillator* (14·5 × 9 *cm*) *mounted with its long axis running fore and aft.*

(b) For the track of a target leading due aft (i.e. parallel to the longitudinal axis of the oscillator) at a depth of 56 fathoms.
(c) A similar curve at a depth of 37 fathoms.
(d) For the track of a target leading 45° forward of the beam. The maximum between 8° and 9° is where the track crosses the transverse axis.
In (b), (c) and (d) the transverse curve and its fitted regression (dotted) are shown for comparison. From these curves, adjustments were made to the 15° amplitudes as described in the text.

range of ϕ concerned, it was effectively the same as the curve for the major axis, and the data are interpreted accordingly. The full line of Figure 27(a) is the theoretical curve for the major axis, the broken line being the linear regression fitted to that part of it covered by the observations (values of ϕ between 8° and 22°). This regression gives an extinction angle (ϕ_0) of 24·3° to be compared with those of column G from the observed regressions,

the mean of which is 24·8° for the corresponding stations. It should perhaps be mentioned at this point that the extinction angle defined in this way is, of course, considerably less than the 'first zero' of the true directivity curve for the major axis, which is about 34° (see Figure 27(a)).

At stations 159 and 200 the wire led aft, which brought the target more towards the minor axis of the sound-cone, where the beam was narrower. The full lines of Figure 27(b) and (c) show the theoretical directivity curves for the track of the target at these two stations with the major axis curve for comparison. Linear regressions are fitted, as before, to those parts of the curves covered by the observations, and give theoretical extinction angles of between 18° and 19°. This agrees well with the observed value at station 200 (19·5°); at station 159 the observed value was 22·7° which is rather higher than the expected value although not significantly so.

Lastly, at station 210, the direction of the wire was about 45° forward of the beam. The track of the target in this case produces a rather peculiar theoretical curve which has a maximum at about 9° caused by the target passing through the major axis when subtending this angle to the vertical (see Figure 27(d)). At greater angles, however, the curve does not differ much from that for the major axis and gives a theoretical extinction angle of 23·6°. The observed value of 28·5° is appreciably higher and is, in fact, higher than the maximum possible theoretical value of 24·3° along the major axis; this is discussed below.

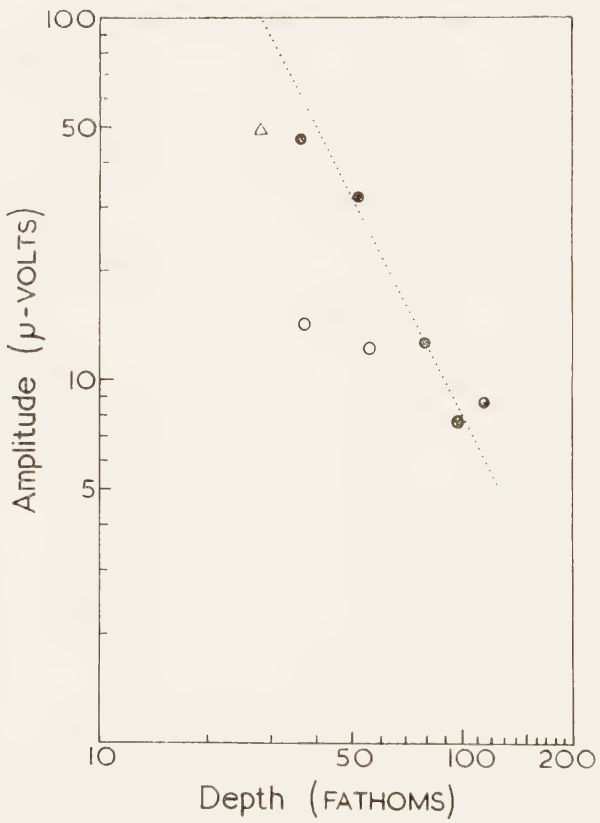


Fig. 28(a). *Relation between signal strength and target depth.*

Plot of the 15° amplitude against depth at each station.

● indicates stations where the wire led abeam.

○ indicates stations where the wire led due aft.

△ indicates a station where the wire led 45° forward of the beam.

The dotted line is a regression with a negative slope of two, fitted to those stations where the wire led abeam. The other stations are clearly not comparable.

Fig. 28(b). *Relation between signal strength and target depth.*

Revised plot of 15° amplitude against depth, using adjusted values for stations at which the wire led other than abeam. Stations 159 and 200 are now in line with the others, but St. 210 (△) is still significantly lower than might be expected. A possible explanation of this is discussed on page 35. The fit of the other stations to the dotted regression line shows that the change of signal strength with depth is adequately described by the inverse square relation.

Turning now to the general relation between signal strength and target depth, the 15° amplitudes at various depths, taken from the observed regressions, are given in column F of Table IV and plotted on a double logarithmic scale in Figure 28(a). In this diagram, the values for the first five stations listed in Table IV, which refer to the transverse axis, are shown as solid circles, those for stations 159 and 200 by hollow circles, and that for station 210 by a triangle. The dotted line is a regression with a negative slope of two, fitted to the solid circles, which shows that the change of signal strength with depth for these stations is adequately described by the inverse square relation. The values for the other three stations, and especially those for stations 159 and 200 where the wire was leading aft, are clearly not comparable, being much lower.

So that all the data could be used to test the depth relation, values for stations 159, 200 and 210 have therefore been adjusted to what would have been expected at those depths had the target moved along the major axis. The factors required were taken from the directivity curves already shown in Figures 27(b)–(d). For example, Figure 27(b) shows that at 15° on the directivity curve for station 200, the amplitude should have been only about one-third of that at the same angle on the major axis, the exact ratio being 0·326. Dividing this into the observed amplitude of 14·6μv gives an estimated 46·3μv for the 15° amplitude that would have been recorded at this station had the wire led abeam instead of aft. This result is tabulated in Column E of Table V, together with the values for stations 159 and 210 adjusted in a similar way.

Table V: *Trawl-float experiments: Adjusted 15° amplitudes for stations at which the target-float did not lead directly abeam*

A	*B*	*C*	*D*	*E*
Station	*Depth*	*Direction of wire*	*Observed 15° Amplitude*	*Adjusted 15° Amplitude*
200	37	Aft	14·6	46·3
159	56	Aft	12·2	33·7
210	28	45° forward	49·3	52·8

Figure 28(b) shows the revised plot of 15° amplitudes against depth, using the adjusted values of Table V. The values for stations 159 and 200 are now accurately in line with the transverse stations, which shows that the experimental technique could follow the radial asymmetry of the directivity pattern with some precision. The amplitude at station 210, however, which required only slight adjustment for direction, remains at not much more than half the value expected from the inverse square relation fitted to the remaining points, which is a significant discrepancy. Had the extinction angle also been low at this station, a possible explanation would have been that the target had actually moved further forward, and hence more into the narrow part of the sound-cone, than was apparent from the direction of lead of the wire. In fact, as already noted, the extinction angle at station 210 was the largest recorded; for the same reason, a drop in power output of the oscillator is not an entirely satisfactory explanation, since in this case the extinction angle should not have been affected.

In these circumstances, it is perhaps worth recording that at station 210 the paper record showed the presence of a fairly dense scattering layer from the surface down to about 15 fathoms, as shown in Figure 29(b). A scattering layer was also present at station 194, but was less dense and extended down to 35 fathoms (see Figure 29(c)). There was no scattering layer at the remaining stations, of which Figure 29(a) is a typical example. Now, if the scattering layer at stations 194 and 210 was sufficient to have influenced to a detectable degree the characteristics of the sound-beam transmitted and reflected through it, dispersion of the beam and perhaps some absorption of energy would be expected. In this connection, it is of interest to note that at station 194, as at station 210, the 15° amplitude was lower and the extinction angle higher than expected. An increase in extinction angle from 24° to 28°, as could have happened at those two stations, means that the area insonified by the sound-beam is increased by roughly 30%. Thus, if there were a corresponding fall in the amplitude of the signal received from a target at any point within this wider beam, correcting the 15° amplitude observed at station 210 accordingly would increase it to nearly 80μv, which is well within the 95% confidence limits for the inverse square regression based on the remaining points.

It would therefore seem possible that the scattering layer at stations 194 and 210 could have been responsible for the relatively low 15° amplitudes recorded there, but it must be emphasized that the evidence presented here is in no sense conclusive. More critical data and a more rigorous theoretical treatment would be needed to establish properly whether the presence of a scattering layer may have to be allowed for when determining fish abundance by quantitative echo sounding.

The analysis of echoes from single fish in the second section of this paper requires a knowledge of the geometry of the sound-cone and of the effective power of the transmitted signal. The latter can be defined in terms of the amplitude (a) of echo received from the standard target situated on the vertical axis of the sound-cone at depth D by the equation

$$a \quad \frac{k}{D^2} \qquad (3)$$

Thus k is a function of the power of the transmitted signal and the reflectivity of the trawl-float target. In the present investigation, measurements could not be made with the target situated axially, but from Figure 27(a) it is seen that the amplitude of an echo from a target subtending an angle of 15° on the major axis of the sound cone would be 0·43 of that obtained if the target were situated on the axis at the same depth. The mean value of the product aD^2 from the 15° amplitudes of all stations except 210 is $8{\cdot}2 \cdot 10^4$, and dividing by 0·43 gives the estimated signal from the target at 1 fathom distant on the axis as

$$k = 1{\cdot}9 \times 10^5 \ \mu\text{-volts}$$

It can be said, in conclusion, that to find a close agreement between the observed directivity pattern and that predicted from the dimensions of the oscillator is perhaps no more than would be expected. It is of some importance, on the other hand, for the future use of echo sounding in fishery research, to find that the power of the signal transmitted from the echo sounder in question, and that of its echo from a target at depths up to 120 fathoms, were certainly up to the standard of consistency required for the estimation of fish abundance.

ANALYSIS OF FISH TRACES FROM PAPER RECORDS

The experiments already described were carried out at suitable opportunities during an echo-survey made in the summer of 1956 to determine the distribution of cod in the western Barents Sea. The paper recorder was run continuously during the survey and a great many fish traces were recorded, some of which were of a clearly defined 'comet' shape. The formation of this type of fish trace has been worked out by Craig (1955) and Cushing (1957). The latter author has further distinguished a particular kind of comet trace in which the pulse length is the same throughout—i.e. at all ranges; this he calls a 'fingernail' trace, and it can be regarded for practical purposes as caused by a single fish. The second part of this contribution is concerned primarily with an analysis of the fingernail traces of fish recorded during the cruise, the results of which are compared with those given in the first section of this paper from experiments using the same oscillator but with a trawl float as target.

While on survey, the ship steamed at about 10 knots, and it seems reasonable to assume that this was considerably faster than the speed at which the fish were usually swimming.* Thus we shall take it that as the ship passed over the fish, the latter described chords across the area insonified by the sound-beam at the depth in question, these chords being parallel to the minor axis of the insonified area. The apparent depth of the top of the comet on the paper record is the range of the fish from the oscillator when it crosses the major axis of the sound-cone. Let this range be R, and the height of the comet (measured from the top to the extreme tip of the tails) be C; then the half-width of the chord (r) described by the fish in question is

$$r = \sqrt{(R + C)^2 - R^2} \quad .. \quad .. \quad .. \quad .. \quad (4)$$

The derivation of this expression is shown diagrammatically in Figure 30. If echoes are received from a number of similar targets at various depths, the average width of chord produced by them at each depth can be calculated from equation (4); since this is an effectively constant fraction of the width of the minor axis of the sound-cone down to the MRS (minimum recordable signal) level at that depth and for targets of that reflectivity, the value of k, which we shall call the "standard signal", can be calculated.

From the practical point of view there are two important considerations. The first is that the comets used for this analysis should be caused, as far as possible, by single fish of the same species and of roughly the same size or, at least, whose size is not correlated with depth. A number of trawl hauls were made during the survey, and nearly all the fish caught

*That the fish tended to remain at least at the same depth whilst the ship was passing over them is indicated by the symmetry of the majority of the comets.

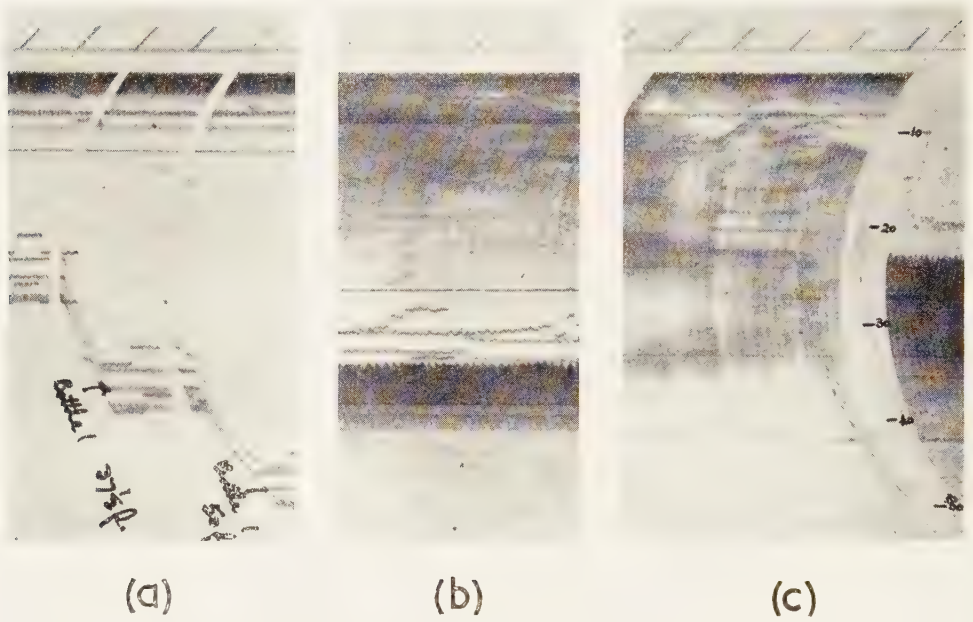


Fig. 29. *Echo-paper records of three stations.*

(a) St. 191 (52 fm) where there is no scattering in the upper layers.
(b) St. 210 (28 fm) where there is dense scattering in the surface 15 fathoms.
(c) St. 104 (97 fm) where the scattering is less dense than at St. 210, but extends to 35 fathoms.
At the latter two stations, the 15° amplitudes are lower and the observed extinction angles greater than would theoretically be expected. It is thought, but by no means proven, that the scatter in the surface waters at these two stations may have been responsible for these anomalies.

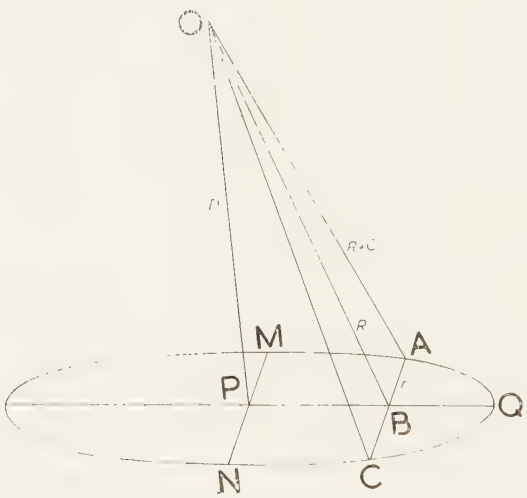


Fig. 30. *The relation between depth and range for fingernail traces and the shape of the MRS area of the sound-cone drawn from theoretical directivity curves.*

O is the oscillator, MPN the minor axis of the sound-cone, and PQ the major axis. ABC is the average chord described by the passage of fish across the MRS area parallel to the minor axis. The ratio of the mean half-width of the MRS area (r_m) to the maximum half-width (= $\frac{1}{2}$ minor axis PM) is 0·82.

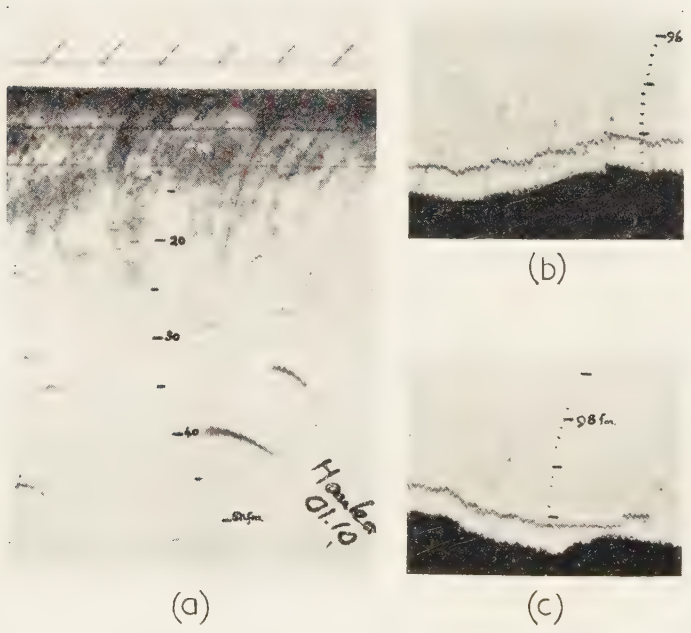


Fig. 31. *Typical fingernail traces.*

(a) Midwater traces between 20 and 50 fathoms range recorded at a speed of approximately 3 knots. Note that nearly all the smaller traces are of uniform thickness, i.e. they are of a single pulse length. The two largest traces are of more than one pulse length and hence are probably caused by small shoals of fish: traces such as these are not included in the measurements.

(b) and (c) Fingernail traces from deep water close to the bottom, obtained while steaming at 10 knots. Notice that all these traces are of single pulse length.

were cod; it is, in fact, general experience in the western Barents Sea that the occurrence of other species such as haddock and coalfish in quantities comparable with those of cod is rare. The single pulse length criterion referred to above was used to identify comets caused by single fish and some examples of both single and multiple pulse length comets are shown in Figures 31(a)–(c). No direct test of fish size could be made, because the fish caught by the trawl were so close to the bottom that their comets were interrupted by the bottom echo and could not be used. Nevertheless, there were many instances in which what could be seen of such comets appeared to be identical to others scattered throughout much of the water column from the bottom upwards (e.g., Figures 31(b) and (c)). It is known that in the summer months the cod adopt a semi-pelagic habit (Trout, 1957); as a corollary there is no very marked correlation between depth and size of fish at this time of year. In the present case, about 80% of the fish caught were between 45 and 75 cm in length with an average of about 60 cm. No hauls were made, however, in water shallower than 30 fathoms, and it is possible that some of the shallowest midwater comets (i.e. those less than 30 fathoms deep) were caused either by smaller cod or even by fish of another species, such as herring or polar cod (*Gadus saida*). Nevertheless, the results from these fitted in well with those from deeper water and there seems no positive reason to reject them.

The other requirement is that the strength of the minimum recordable signal on the paper record should be known and remain constant since, other things being equal, the MRS level determines the height of the comet. A difficulty here is that the paper sensitivity is liable to vary to some extent from one roll to the next, but the trawl-float experiments provided many opportunities during the survey to compare the paper record with the CRT calibration and no obvious discrepancies were found. The MRS level on the paper record was similar to that of the CRT, i.e. in the region of $4\mu v$. This refers, of course, to a particular setting of the gain control for the paper record, which was matched to the CRT amplification by means of a signal injector and kept the same throughout.

1. THEORETICAL

To interpret estimates of the width of the area insonified at various depths from measurement of comet-height, we use the approximate treatment of the directivity theory already put forward, in which the relation between amplitude of echo and vertical angle subtended by the target is taken as linear.

Suppose the vessel passes over a stationary fish target so that the track of the latter across the insonified area coincides with the minor axis.

Let A = amplitude of echo received when target is on the vertical axis of the sound-cone

a = amplitude of echo received when target subtends an angle ϕ to the vertical axis in the plane of the minor axis

r = horizontal distance of target from vertical axis when it is subtending angle ϕ

D = vertical depth of target below the oscillator

Assuming a linear directivity pattern, the echo amplitude when the target subtends an angle ϕ can be expressed as a ratio of the echo amplitude when the target is on the vertical axis at the same depth by the equation

$$a/A = 1 - b\phi$$

where b is the slope of the linear approximation to the directivity curve.

We now make the substitutions

$$\phi = \tan^{-1} r/D$$

$$A = \frac{k}{D^2}$$

$$b = \frac{1}{\phi_0}$$

where k is the "standard signal" for the target in question (see p. 36) and ϕ_0 the extinction angle (see p. 33), giving

$$aD^2/k = 1 - \frac{1}{\phi_0} \tan^{-1} r/D$$

On rearranging, this becomes

$$r = D \tan \left[\phi_0 \left(1 - \frac{a}{k} D^2\right) \right] \quad .. \quad .. \quad .. \quad (5)$$

which is an expression defining the distance r of the target from the vertical axis when it is generating an echo amplitude a. A special case of this arises when the target is generating the minimum recordable signal (a_m) near the edge of the insonified area; its distance from the vertical axis is now one-half of the minor axis (r_m) of the MRS area at the depth in question, and from equation (5) we have

$$r_m = D \tan \left[\phi_0 \left(1 - \frac{a_m}{k} D^2\right) \right] \quad .. \quad .. \quad .. \quad (6)$$

Now, measurements of the height of comet traces generated by targets passing along the minor axis provide estimates of r_m, but to apply equation (6) to actual comet-heights obtained from fish echoes, allowance has to be made for two practical considerations. The first is that measurements of a number of comet-heights at a particular range give an estimate not of r_m directly but of the mean width of the MRS area parallel to its minor

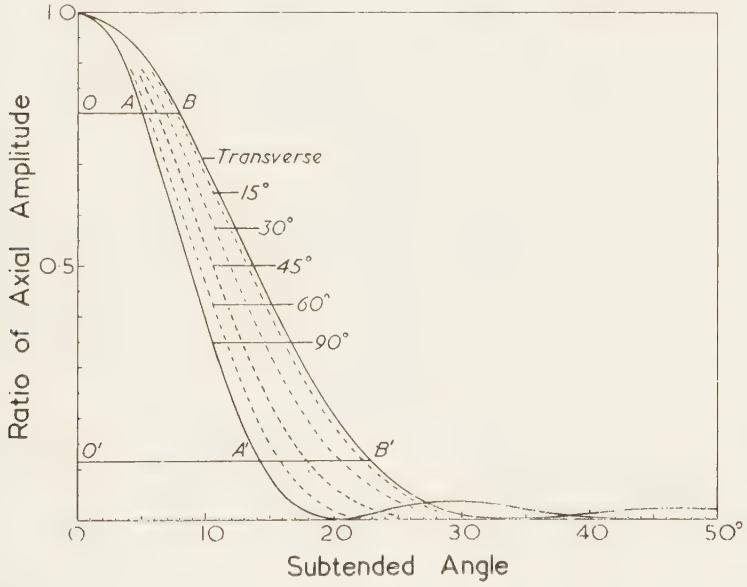


Fig. 32. *Theoretical directivity patterns for the major* (0°) *and minor* (90°) *axes and for intermediate values of* $\psi = 15°, 30°, 45°$ *and* $60°$.

$\frac{OA}{OB} = \frac{O'A'}{O'B'}$; in other words the ratio of the minor to the major axis of the sound-cone is constant throughout, so that the shape of the MRS area will be the same at all depths. Hence the mean width of the MRS area will be a constant fraction of the maximum width, i.e. of the minor axis.

axis. The shape of the MRS area remains effectively the same at all depths, however, as can be seen from the true theoretical directivity curves of Figure 32. Hence the mean $\frac{1}{2}$-width of the MRS area ($\bar{r}_m$) is a constant fraction of the $\frac{1}{2}$-width of the minor axis, and we can put

$$\bar{r}_m = x r_m$$

where x is a constant which can be estimated from the theoretical directivity pattern of the oscillator.

The second complication arises from the fact that the minimum range of a small target can be determined from the paper record, but not its true vertical depth. The two can, however, be related in the following way, with reference to Figure 30. At a given depth, the mean MRS $\frac{1}{2}$-width ($\bar{r}_m$) can be visualized as a line AB (or CB) intersecting the major axis at a certain distance PB from the vertical axis OP, this distance being the fraction y of the major $\frac{1}{2}$-width PQ ($= r'_m$). The mean minimum range OB ($= \bar{R}$) which is the distance from the oscillator (O) to the point B is therefore related to depth by the expression

$$OB^2 = OP^2 + PB^2$$

or

$$\bar{R}^2 = D^2 + (yr'_m)^2$$

But r'_m is itself given by an expression exactly analogous to equation (6), except that the extinction angle is now that measured along the major axis. Calling this angle ϕ'_0, we have:

$$r'_m = D \tan\left[\phi'_0 \left(1 - \frac{a_m}{k} D^2\right)\right]$$

so that

$$\bar{R}^2 = D^2\left[1 + y^2 \tan^2\left\{\phi'_0 \left(1 - \frac{a_m}{k} D^2\right)\right\}\right] \quad .. \quad .. \quad (7)$$

It will be noted that because this expression contains the "standard signal" k, there is no fixed relation between depth and range. The procedure we have adopted is therefore, in the first instance, to treat depth as synonymous with range so that an approximate estimate of k can be obtained from equation (6); this is used in equation (7) to convert range to depth so that a revised estimate of k can be obtained from (6).

2. RESULTS

Measurements of the height of 288 fingernail traces, at minimum ranges from 10 to 120 fathoms, are given in Table VI as a frequency-distribution, the heights being measured to the nearest tenth-fathom and the range data being grouped in intervals of 10 fathoms. It will be noticed that the comet-height increases rapidly with range at first, but at greater ranges the increase is less and eventually ceases.

The form of this trend is brought out more clearly in Table VII, where the mean comet-heights in each 10-fathom range interval, and the corresponding mean minimum ranges are tabulated in columns D and C. Column E gives the mean $\frac{1}{2}$-width of the insonified area, calculated from the theoretical directivity curves as 0·82. Using this value, and taking range and depth to be equivalent, first estimates of a_m/k and ϕ_0 were obtained by fitting equation (6) to the data of columns C and E, these being

$$a_m k = 2{\cdot}1 \times 10^{-5}$$

$$\phi_0 = 15{\cdot}5°$$

Using these in equation (7) together with the theoretical value of $\phi'_0 = 24{\cdot}3°$ (see p. 33) enabled the depths corresponding to the mean ranges of column C to be calculated; these are tabulated in column F of Table VII. Figure 33 shows the mean $\frac{1}{2}$-width of the insonified area plotted against true depth, together with the theoretical curve calculated from equation (6) with

$$a_m/k = 2{\cdot}7 \times 10^{-5}$$

$$\phi_0 = 17{\cdot}6°$$

Table VI: *Single fish traces: Frequency distributions of trace-height at various ranges*

Vertical height of trace (fm)	*Range (fathoms)*										
	10–20	21–30	31–40	41–50	51–60	61–70	71–80	81–90	91–100	101–120	121 & *over*
0·1	-	-	-	-	-	-	-	-	-	-	-
0·2	1	-	-	-	-	-	-	-	-	-	-
0·3	3	1	-	-	-	-	-	-	-	-	-
0·4	5	-	-	-	-	-	-	-	-	-	-
0·5	8	4	-	-	1	-	-	-	-	-	-
0·6	7	6	2	-	-	-	-	-	-	-	-
0·7	4	4	1	-	1	-	-	-	1	-	-
0·8	4	5	2	2	-	-	-	-	-	-	-
0·9	3	2	5	-	4	-	-	-	-	-	-
1·0	-	11	8	6	4	1	-	1	2	-	-
1·1	1	3	2	2	4	-	1	-	2	1	-
1·2	-	4	2	6	1	5	1	2	-	-	-
1·3	2	5	2	1	5	1	1	1	2	1	1
1·4	-	2	2	2	-	-	1	2	-	1	-
1·5	-	3	2	5	7	2	1	4	2	2	1
1·6	-	3	2	3	-	1	4	2	4	3	-
1·7	-	-	-	4	3	-	-	2	1	-	-
1·8	-	-	1	5	3	2	-	1	5	1	-
1·9	-	-	1	-	-	-	1	-	1	-	-
2·0	-	-	2	2	3	2	-	3	3	-	-
2·1	-	-	-	-	-	1	-	1	1	1	-
2·2	-	-	-	-	-	-	-	-	-	-	-
2·3	-	-	-	-	-	-	-	-	2	-	-
2·4	-	-	-	-	-	-	-	-	3	-	-
2·5	-	-	-	-	-	-	-	-	2	-	-
2·6	-	-	-	-	-	-	-	-	1	-	-
2·7	-	-	-	-	-	-	-	-	-	1	-
Total	38	53	34	38	36	15	10	19	32	11	2

The fit is satisfactory, although a more critical test would have been possible if there had been observations at depths greater than 120 fathoms. It will be noted that with single cod of roughly 60 cm length as targets, the size of the insonified area reaches a maximum at a depth of about 110 fathoms, and shrinks to zero at about 190 fathoms. Although an exact comparison is not possible, the estimated value of ϕ_0 should be approximately the same as the linearly extrapolated extinction angle calculated from the lower part of the theoretical

Table VII: *Summary of measurements of single fish traces, and calculated width of sound-cone at various depths (see Figure 33)*

A	*B*	*C*	*D*	*E*	*F*
Range (fm)	*Number of Observations*	*Mean range (fm)*	*Mean height of trace (fm)*	*Mean ½-width of sound-cone (fm)*	*Calculated depth (fm)*
10–20	38	16·45	0·62	4·46	15·8
21–30	53	24·92	0·98	6·97	24·0
31–40	34	36·09	1·17	9·14	34·7
41–50	38	45·08	1·37	11·07	43·5
51–60	36	55·58	1·33	12·12	53·7
61–70	15	64·27	1·51	13·88	62·2
71–80	10	76·70	1·48	15·13	74·4
81–90	19	86·89	1·58	16·57	84·5
91–100	32	96·06	1·78	18·44	93·7
101–113	11	104·10	1·65	18·50	101·7
122–124	2	123·00	1·40	18·60	120·7

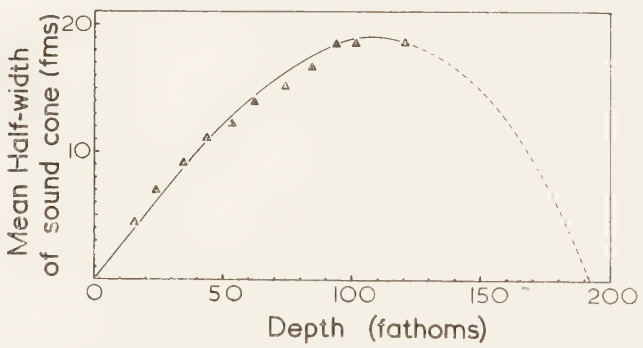


Fig. 33. *The mean half-width of the sound-cone plotted against true depth.*

▲ = observed mean half-widths. The line is the theoretical curve calculated from equation 6 (page 41) using the values

$$\frac{a_m}{k} = 2{\cdot}7 \times 10^{-5} \text{ and } \phi = 17{\cdot}6°$$

directivity curve for the minor axis. This can be seen from Figure 32 to be about 17°, which agrees well with the estimated value.

The estimate of greatest significance, however, is that of the "standard signal" k for cod of average length 60 cm, and taking the MRS as $4\mu v$ gives

$$k = \frac{4}{2{\cdot}7 \times 10^{-5}} = 1{\cdot}5 \times 10^5 \ \mu\text{-volts}$$

It will be noted that this does not differ much from the value of k found in the first section of this paper for the standard 8″-diameter trawl float ($1{\cdot}9 \times 10^5$), and it is of importance to find out whether this same relativity applies also to the signal strengths of the echoes

obtained simultaneously from a float and a 60 cm cod under controlled conditions when the two are placed close together in the sound-cone. The practical difficulties of attempting this at sea are those of suspending at a controlled depth and in a natural position, a live fish with an intact and properly functioning swimbladder. The first comparative trials were made by Jones (this publication, Part III), using an 8″-diameter trawl float and a dead 85 cm cod; he found that the fish gave an echo about 1·3 times that of the float, but its swimbladder was almost certainly ruptured.

At his suggestion, we have repeated the experiments using a dead cod of 75 cm with the swimbladder (a) intact, (b) ruptured, and (c) replaced by an artificial bladder shaped from a block of expanded rubber*; the latter was also tested separately. The fish was attached to a wire carrying a heavy weight and hung as nearly as possible in a natural position; an 8″-diameter trawl float was fastened two fathoms below it. The ratios of the signals from the fish to those from the float at various ranges are summarised in Table VIII and plotted in

Table VIII: *Comparison of echo amplitude from cod and a trawl float at various depths*

	Range (fathoms)	*Ratio:* $\frac{\textit{Fish signal}}{\textit{Float signal}}$
Cod with swimbladder	13·8	1·16
Cod with swimbladder	37	0·64
Cod with swimbladder	55	0·88
Cod with swimbladder	59	0·77
Cod with artificial swimbladder	27	1·00
Cod without swimbladder	27	1·13
Cod without swimbladder	55·5	0·56
Artificial swimbladder only	27	0·49
Artificial swimbladder only	55·5	0·22

Figure 34. All the ratios tend to decrease with range (and hence also with depth), presumably owing to the effect of pressure on the artificial swimbladder and the dead fish, in which a small amount of air may have been trapped despite attempts to prevent this; but rather unexpectedly no clear differences between any of the fish ratios are apparent, whatever the state of the swimbladder. This result may well be due to faulty technique and the experiments certainly need repeating, but the fact that the signals from the artificial swimbladder alone (about 1/20 of the volume of the fish) are about half those from the fish suggests that as a working figure, it could be assumed that the swimbladder in a live cod does not contribute more than about one-third of the total signal. This is in harmony with the results obtained by Jones and Pearce (1958) on perch (*Perca fluviatilis* Linn), in which species the relatively large swimbladder (about 7% of the volume of the fish) is responsible for about one-half of the total echo, and also with the earlier work of Cushing and Richardson (1955) who concluded that between 40% and 80% of the echo received from a live cod comes from the swimbladder.

On this basis, the data of Table VIII and Figure 34 indicate that the strength of echo from a 75 cm live cod would be at the most about 1½ times that from an 8″-diameter float; while adding 50% to the value of 1·3 obtained by Jones gives a ratio of about 2 for an 85 cm cod. To adjust each of those ratios to the maximum values that would have been

*The material used is 'Onazote', a rigid expanded vulcanized rubber manufactured by the Expanded Rubber Company Limited, Croydon, England. It is supplied in sheets which can easily be cut and shaped with a knife and sandpaper. Jones and Pearce (1958) have shown that an artificial swimbladder made of Onazote has acoustic reflection properties closely similar to those of a natural bladder of the same size.

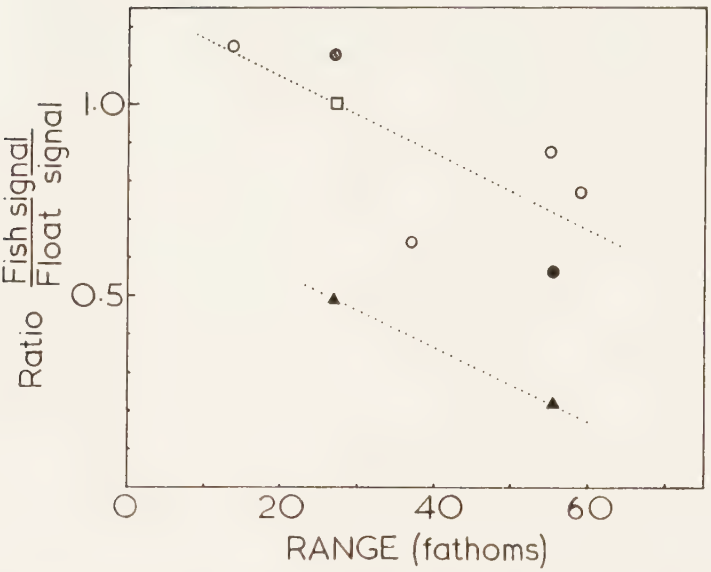


Fig. 34. *Comparison of the reflected signals from an 8″-diameter trawl float and a 75 cm cod at various depths.*

○ indicates 75 cm cod with swimbladder.
● indicates 75 cm cod with ruptured swimbladder.
□ indicates 75 cm cod with an artificial swimbladder.
▲ indicates the artificial swimbladder alone.
The lower ratios from the greatest depths are probably due to the effect of pressure on the dead fish and the artificial swimbladder.

expected from a 60 cm fish we have reduced them according to the ratios of the cross-sectional areas of fish of these sizes, giving

$$1\tfrac{1}{2} \times 60^2/75^2 \sim 1$$

$$\text{and also } 2 \times 60^2/85^2 \sim 1$$

Thus the data available so far on the relative strengths of echoes obtained from single cod and an 8″ trawl float are consistent in showing that the reflectivity of such a float and a cod of 60 cm length should be about the same. This is, of course, in accordance with the result obtained from the analysis of comet-heights from the echo-survey records; this has the corollary that there is apparently no substantial difference between the acoustic reflectivities of live and dead fish. Although the accuracy of neither sets of data is very high, the indications from these experiments are that the signals received from single cod (and presumably other single fish of similar size) during echo-survey can be treated as if they came from simple targets and can be interpreted satisfactorily by means of the approximate directivity theory developed in this paper.

SUMMARY

1. A method is described by which the acoustic properties of a vertically transmitting echo sounder may be determined experimentally in deep water at sea.
2. The method was applied at various depths from 30 to 120 fathoms, using an 8″-diameter steel trawl float as a standard target. It was found that the theoretical directivity pattern of

the oscillator could be followed satisfactorily, and that the general relation between strength of the signal echo and depth obeyed the inverse square law.

3. An approximate directivity theory is developed and used to analyse the dimensions of the 'fingernail' traces of single cod obtained during echo-survey in the western Barents Sea. From these data, the change of the effective size of the insonified area with depth is deduced, and application of the directivity theory gives an estimate of the "standard signal" for single cod (average length 60 cm); this is very similar to that for an 8″-diameter trawl float.

4. The same relativity was established between the strength of echoes received (after allowing for the contribution of the swimbladder) from a dead cod and from a trawl float when the two were suspended close together in the sound-cone.

5. It is concluded that with the echo sounder used, the precision with which signals could be transmitted and echoes received from fish in depths down to at least 120 fathoms was certainly up to the standard necessary for quantitative fish-survey. The evidence is that single cod behave acoustically as simple targets, and that the echoes from them can be analysed satisfactorily by means of the approximate directivity theory developed herein.

APPENDIX II

CALCULATION OF THEORETICAL DIRECTIVITY PATTERN

The oscillator used in the experiment was a rectangular bar-oscillator (14·5 cm × 9 cm) with its long axis running fore and aft.

The equations for the pressure due to the transmitted signal at any point within the sound-cone, as a ratio of the axial pressure at that range, have been given by McLachlan (1934, p. 100). These, however, express the location of the point in terms of direction cosines, whereas for the present purposes it was necessary to transform the equations so that the target was located with reference to the angle (ϕ) it subtended to the vertical axis of the sounder and the direction (ψ) of the vertical plane, measured from the long axis of the oscillator, in which that angle is subtended.

The equations were multiplied by $\cos\phi$ to allow for the fact that in the experimental set-up used, different values of ϕ were generated by moving the target in a horizontal plane, thus causing its range to vary as the cosine of the angle itself. Finally, the whole expression was squared, since the amplitudes measured were those of the signal received back at the oscillator after reflection by a relatively small target.

The general equation, with the target subtending angle ϕ in a vertical plane ψ, is

$$R = \left[\frac{\sin\left(\frac{2\pi a}{\lambda}\sin\theta\cos\chi\right)}{\frac{2\pi a}{\lambda}\sin\theta\cos\chi} \cdot \frac{\sin\left(\frac{2\pi b}{\lambda}\cos\theta\right)}{\frac{2\pi b}{\lambda}\cos\theta} \right]^2 \cos^2\phi$$

where

$$\cos\chi = \sqrt{\frac{\cot^2\psi}{\operatorname{cosec}^2\psi\,\operatorname{cosec}^2\phi - 1}}$$

$$\cos\theta = \sin\phi\sin\psi$$

and

$$R = \frac{\text{received amplitude of reflected signal}}{\text{amplitude of reflected signal with target on axis}}$$

λ = wavelength of transmitted sound (= 5 cm)

$2a$ = width of oscillator (= 9 cm)

$2b$ = length of oscillator (= 14·5 cm)

The equations for the directivity pattern in the planes of the transverse or longitudinal axes of the oscillator can be obtained from this equation by putting ψ = zero or 90°, respectively. They are, for the transverse plane

$$R = \left[\frac{\sin\left(\frac{2\pi a}{\lambda} \sin\phi\right)}{\frac{2\pi a}{\lambda} \sin\phi} \right]^2 \cos^2\phi$$

and for the longitudinal plane

$$R = \left[\frac{\sin\left(\frac{2\pi b}{\lambda} \sin\phi\right)}{\frac{2\pi b}{\lambda} \sin\phi} \right]^2 \cos^2\phi$$

V. A NEW METHOD OF ECHO-SURVEY AT FULL SPEED

by D. H. Cushing

INTRODUCTION

It is a short step to apply the catch-signal relation to use on echo-survey; it is again assumed that the power output of the echo sounder remains constant during the survey and that the signal-to-noise ratio also remains constant. There was no means available of checking the power output of the sounder, save that we know that the electrical conditions for transmission were the same. However there is no significant difference between the observations on the catch-signal relation taken in July, 1955 and those taken in June, 1956. Again, when we lowered an 80 cm cod (ungutted) over the side in calm weather on a wire in June 1956, the returned signal was about 23 to 35μv at 55 fathoms. Interpolating from Dr. Jones' results in September, 1955, we find that an 80 cm cod at 55 fathoms then would give a signal of about 25μv; as both observations were taken on the wire from the plankton winch in calm weather with the wire vertical, it is probable that the fish in both observations were in about the same position relative to the axis of transmission. From two independent lines of evidence, we believe that during the period under examination the echo sounder was fairly constant in its power output.

THE USE OF A STALKED OSCILLATOR

During Cruise V, ernest holt, 1955, the number of signals missing due to aeration during a five-minute count (300 transmissions) often amounted to 50–100; recording was stopped when the number rose to 150 because the loss of information would then become serious. In order to overcome this effect of aeration, the transmitter and receiver were built into a 'fish' on an extensible stalk. At rest, the 'fish' was housed in a fairing close to the keel; in action, it was extended two feet vertically downwards from the ship's hull. The whole arrangement was built by Messrs. Kelvin and Hughes Limited.

Table IX shows the order of reduction of missing signals with the sounder down.

Table IX: *Comparison of number of missing signals per 5-minute count with the sounder up or down*

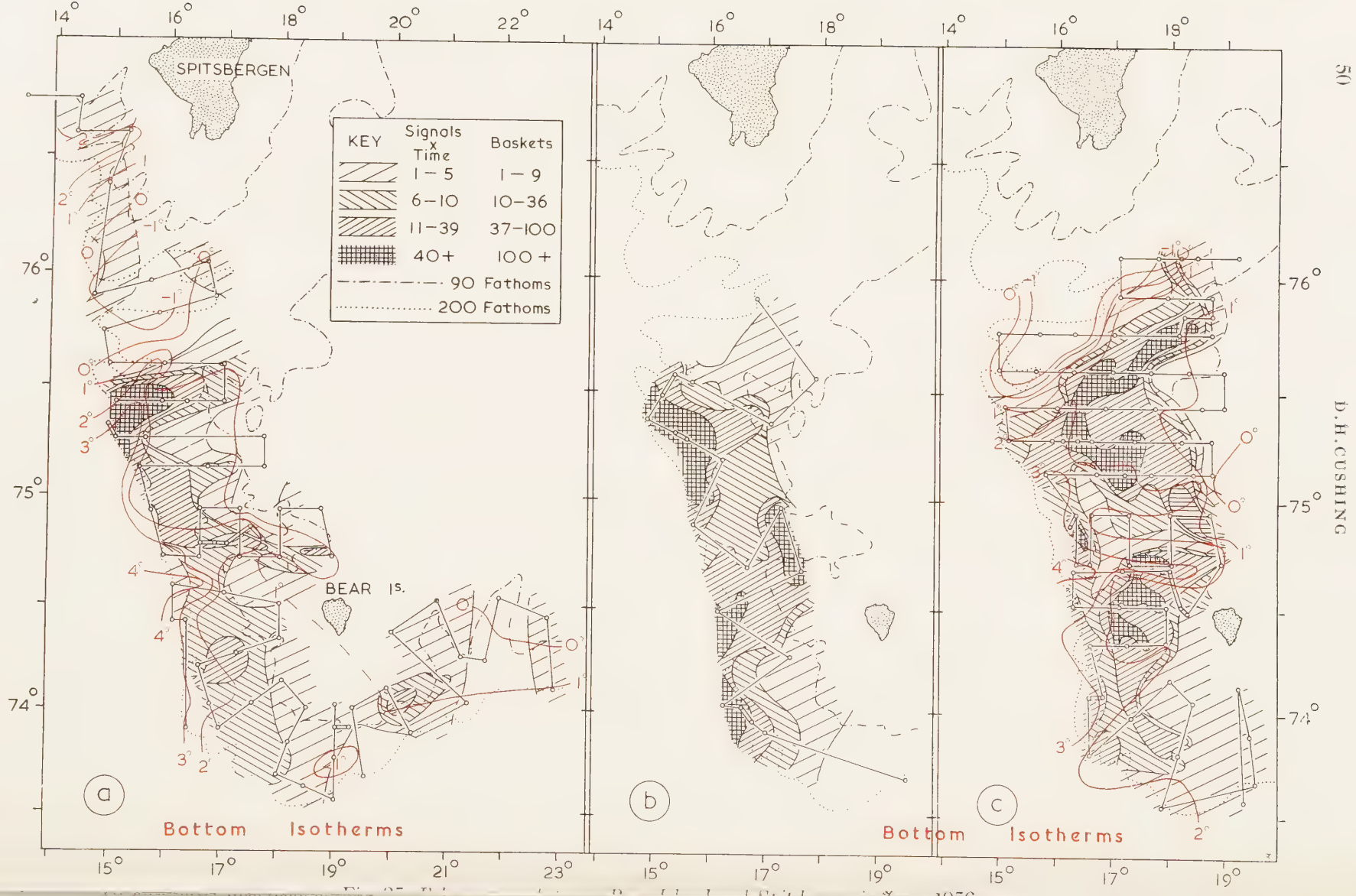
SEQUENCE	*UP*	*DOWN*
Period 1	–	1
Period 2	–	0
Period 3	55	–
Period 4	37	–
Period 5	32	–
Period 6	35	–
Period 7	–	0
Period 8	–	0
SEA 2	SWELL 2	
Period 1	–	0
Period 2	58	–
Period 3	81	–
Period 4	–	0
SEA 3	SWELL 4	

During the whole of Cruise VI, ERNEST HOLT, 1956, the number of missing signals never arose above 50 in each five-minute period (and was usually less than 25) even under quite bad conditions; this was a considerable improvement on the recording on Cruise V, ERNEST HOLT, 1955, when we experienced 30 to 120 missing signals out of 300 in each five-minute period.

However, with the sounder down, there was an increase in water-noise, perhaps because the transducers were more vulnerable to propeller-noise or perhaps because the stalk was vibrating. The test shown in Table X was carried out at full speed in 90 to 130 fathoms of water in a flat calm sea.

Table X: *Noise levels in μv with the sounder up and down*

DEPTH (Fathoms)	*UP*	*INTERMEDIATE*	*DOWN*
100	1·4	–	2·7
90	2·9	–	3·5
90	1·5	–	3·1
115	1·0	–	2·2
121	1·0	–	1·5
130	1·0	1·0	1·5


SPITSBERGEN
KEY
Signals x Time
Baskets
1 – 5
1 – 9
6 – 10
10 – 36
11 – 39
37 – 100
40 +
100 +
90 Fathoms
200 Fathoms
BEAR IS.
14°
16°
18°
20°
22°
76°
75°
74°
15°
17°
19°
21°
23°
a
b
c
Bottom Isotherms
Bottom Isotherms

Thus, there is an increase of noise when the sounder is put down of about 1 μv. At the expense of 1 μv in water-noise, we have found that the stalked oscillator allows us to survey at a speed of at least $9\frac{1}{2}$ knots in all weathers up to a state of sea or swell of 5 and from 50 to 200 fathoms in depth.

THE SIGNAL-TO-NOISE RATIO

The following signal levels on the CRT were used: MRS (the minimum recordable signal), 1, 2 and 3. A signal recorded as 1 occurred between MRS and the wire on the CRT marking the first signal level; similarly, a 2 was recorded as between the signal levels 1 and 2. The amplifier was set so that the signal levels were as follows:—

MRS	7·8 μv.
First	15·8 μv.
Second	25·7 μv.
Third	c. 75·0 μv.

Under such conditions, the water-noise was 3·2 to 1·6 μv. The signals recorded between the signal levels mentioned above would have the following average values:—

MRS — 1	11·8 μv.
1 — 2	20·7 μv.
2 — 3	50·3 μv.

Thus the signal-to-noise ratio on the lowest recorded signals was 5 on the average and 2 to 3 at the minimum. If the water-noise were to increase to 9 μv the amplifier was set so that the first signal level was at 25·7 μv; thus the signal-to-noise ratio was preserved at 3 to 5, but sensitivity was reduced. With the use of the signal generator and the measurements of noise, the signal-to-noise ratio may be maintained so that significant results are obtained all the time, under different conditions of depth, weather and speed.

THE SURVEYS OF CRUISE IV, ERNEST HOLT, 1956

The method of survey is an extension from the catch-signal relationship. The same technique of counting is used exactly; however, as the ship is moving at approximately three times the speed of towing, the density of signals received is reduced to one-third, because a signal from one fish is not repeated so frequently. Signals on survey were plotted in distance on the chart at 15-minute intervals, so the counts are then equivalent to any 5-minute interval during a trawl haul. Then, if necessary, the catch-signal relationship can be used to forecast the catch in any area surveyed.

The purpose of Cruise IV, ERNEST HOLT, 1956 was to try to use a double echo-survey in the Bear Island region to show the movement of fish on to the Bank. This paper is concerned only with the validity of the echo-survey method.

Figure 35(a) shows a survey grid set out between Bear Island and Spitsbergen. The main lines of observation are set to run up the edge of the shelf from about 200 to 50 fathoms; in the South-East Gully, the North-West Gully and in the Storfjordrenna, the pattern of the grid has been shaped to fit the local geography.

The survey information was marked on the cruise track at 15-minute intervals and as the survey progressed, it was possible to build up a picture of the abundance of signals from fish. The chart has been contoured at 1, 5, 10 and 40 units of signal per 15 minutes. An examination of the catch-signal relation will show that these levels are within the range of error in that relation.

The survey shows the presence of a patch of signals on the Bear Island Bank, of a small patch extending up the southern edge of the North-West Gully and of a very dense patch just south of the Storfjordrenna. No signals were recorded on the shallower water of the central Bank at all. In these depths, a difference was noticed in the nature of the bottom signal in that the angle between the time-base and the bottom signal became exceedingly sharp (Figure 36(b)); at other depths it was then noticed that this angle became filled with a tiny nick (Figure 36(a)). The absence of this 'nick' signal became associated with very cold water, so that in the end it was possible to steam towards the shallow water and wait until

Fig. 36. *Diagram of* (*a*) *The signal which disappears in water of* 0°*C.*
(*b*) *The signal which is found in water of* 0°*C.*

the 'nick' signal disappeared; then we would measure the bottom temperature, and find that it was zero. It was thought that this indicated a complete absence of fish; if fish were present, the small 'nick' signal, indicating a signal from the extreme range of sensitivity, would be present in many of the transmissions.

Trawlers were to be found fishing on each of the three patches shown, even on the tiny patch at the head of the North-West Gully. This was a useful check, because the rate at which information was built up with one or two hauls per day was not great. The purpose of such hauls was to check that the survey was still working on cod and not on some other species.

From Spitsbergen, the ERNEST HOLT steamed south in a series of coarse zigzags, surveying all the way. The results are presented in Figure 35(b), as a check to those in Figure 35(a), because the check survey was carried out immediately after the original. It will be seen that the main patches have remained in the same positions except that there has been a movement up either side of the North-West Gully. Further analysis of changes is not worth while because of the coarseness of this grid employed.

Figure 35(c) shows the third survey carried out between the area south of Bear Island and the Storfjordrenna. There are again three patches, one on either side of the North-West Gully, the southern one extending over the Bank, and a major patch south of the 'Renna'. The positions of the patches were again confirmed by the distribution of the trawlers fishing.

Comparison of the three surveys shows that they are consistent enough to deduce some movements. For example, it is probable that fish moved up the North-West Gully and separated into two groups, one of which stayed on the northern edge and the other of which moved south from the southern edge to mix with the fish already there. Again, the dense patch of fish south of the Storfjordrenna moved up the Bank and extended north-east and south-east from the apparent point of entrance. There was a patch of fish present on all three surveys which remained in the deep water west of the Island.

Thus with the use of a double survey, the movement of fish along the bottom up on to the Bank from the deep water has been shown. On the first survey, no fish were recorded in midwater over the deep water at these depths at which they were found on the shelf.

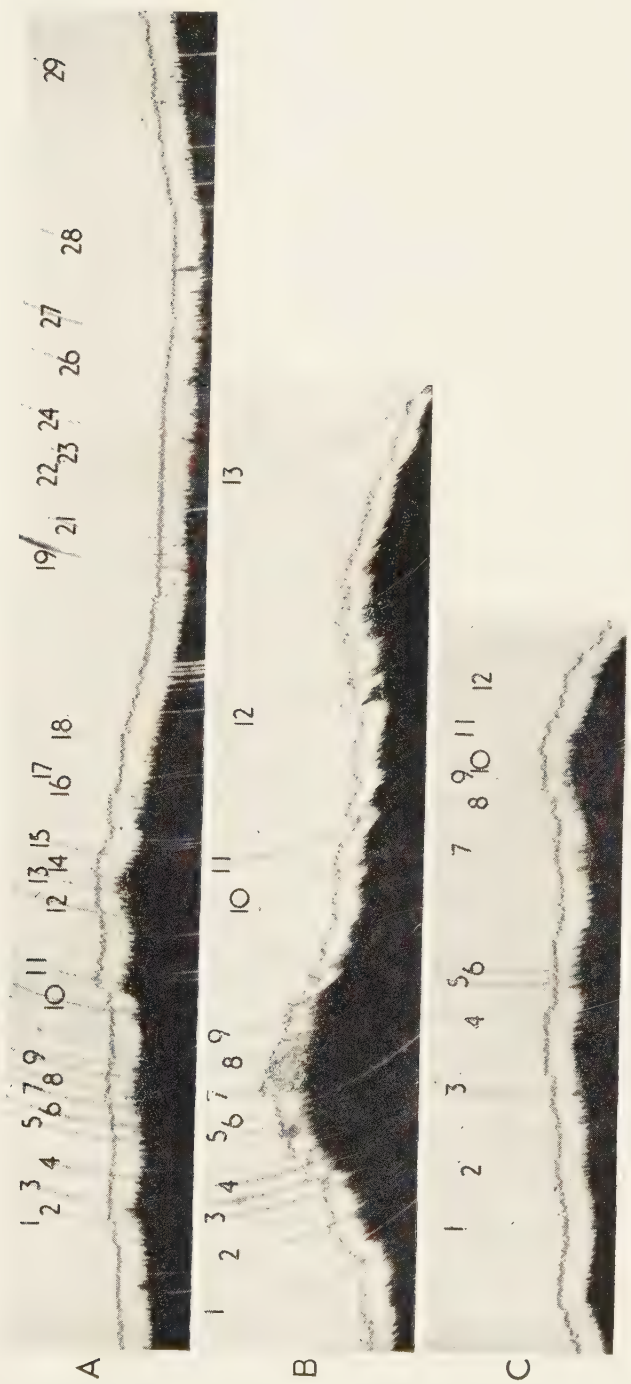


Fig. 37. *The appearance on the paper-record of certain CRT signals from fish close to the bottom.* Three series (A, B and C) are presented from different areas. At the time of observation on the CRT, the recorder marker was pressed. These marks are numbered for reference in the text. It will be noticed that there is a short delay in time between the appearance of the fish trace and the appearance of the reference mark. Note: This is not a "white line" record. The thin line above the bottom record is the marker for the CRT scan.

The signals from fish disappeared at about 180 to 210 fathoms, but whether this was due to the absence of fish or the inability of the echo sounder to record them, is not known. As fish were being caught off the Storfjordrenna at 160 fathoms on the first survey from patches of very dense signals, it is believed that the fish were absent at 180 to 210 fathoms.

COMPARISON WITH PAPER-RECORD SURVEYS

During Cruise V, ERNEST HOLT, 1955, a number of echo-surveys were made using both the CRT method of counting and the paper record. Comparison was made in the following way. Notable signals which lasted for five or more transmissions were marked on the paper record at the time at which they appeared on the CRT. Three types of signal were recorded which are illustrated in Figure 37.

1. Traces clear of the bottom, which are mainly small 'comets' and indeterminate 'mush', probably multiple 'comets'.
   (A; 6, 8, 16, 17, 18, 19, 21, 27, 29
   B; 3–9)
2. Traces of softer colour touching the bottom; again, the shape of the trace was variable.
   (A; 3, 13, 26
   B; 7, 8, 9, 11
   C; 3, 6, 7, 8, 11)
3. Traces which are indistinguishable from the bottom; i.e. they were observed on the CRT but not on the paper.
   (A; 1, 4, 7, 11, 14
   B; 12
   C; 4)

The rest of the traces were of an indeterminate character. There are two types of echo

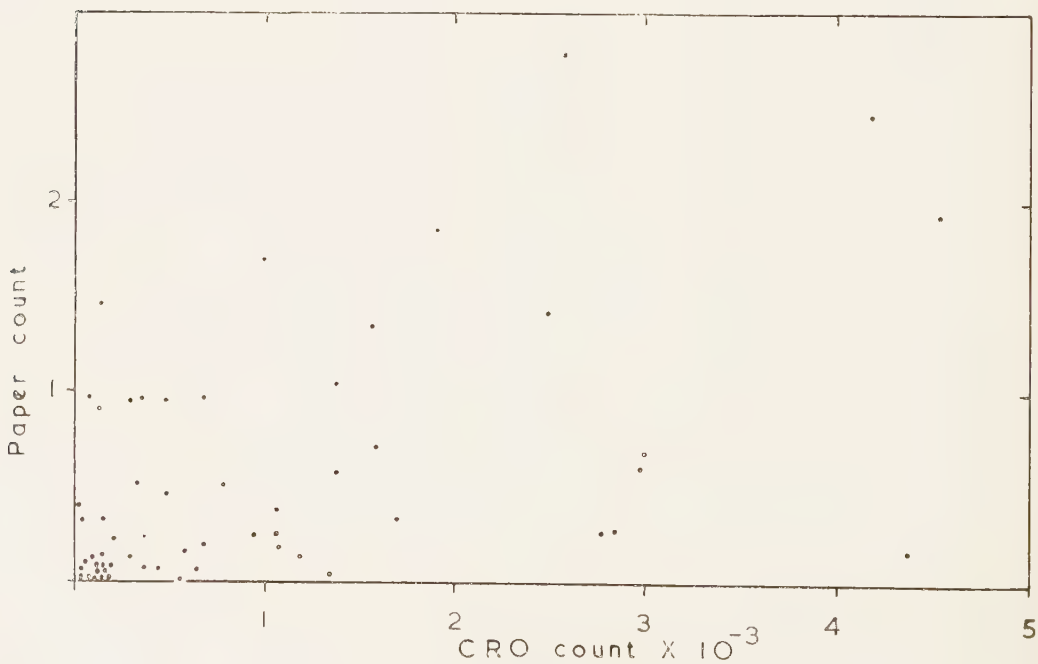


Fig. 38. *Correlation between CRT count and estimated paper-record count.*

which do not appear on the paper, being indistinguishable from the bottom trace:

(a) those of fish quite close to the bottom, the signal intensity of which is the same for fish and bottom. This does not mean that the signal from fish is very strong, but that the paper is overloaded.

(b) small echoes from fish close to the bottom, which are transitory and appear as a nick on the bottom trace.

The paper recorder does not present either signal in such a way that it can be noticed.

A numerical comparison was made in the following way. Each trace was counted as a unit; 'mush' was counted by its width in millimetres multiplied by three, because the mush trace was always an effect of about three comet-type signals becoming superimposed—which we could see on the CRT. Counts of paper traces were added up between stations and compared with the number of signals recorded on the CRT. As the depth was the same for each observation, the depth correction was not used. Figure 38 shows the correlation between the two variables. If, however, it is recalled that a count of 2500 on the CRT in 86 fm represented 120 baskets/hr, it will be seen that the correlation is, from a fishermen's point of view or from the point of echo-survey, useless, and this is because the paper record is so inadequate. It should be noted that no trend with depth was found.

DISCUSSION

Not only is this the first form of echo-survey to be applied to demersal fish, but it is also the first in which changes in the amplitude of received echo have been taken into account. We have been deterred from attempting this in the past because the power output and the signal-to-noise ratio might vary. However, the constancy of the catch-signal relation over a period of one year and the fact that signals from an 80 cm cod in September, 1955 were comparable in magnitude with those recorded in June, 1956, led us to think that the power output was more or less constant; the makers of the instrument used, tell us that in tank-tests, the power output of the oscillators does not vary much more than about 5 to 10% so long as the inductive chargers are properly maintained. It is realised that in future routine work, it would be wise to place a standard target below the echo sounder as a check on the power output.

The method of noise-measurement so as to keep the signal-to-noise ratio under control has been described. In the region under survey we were able to work at $9\frac{1}{2}$ knots up to state of sea 5. If it were necessary to work in shallower water in bad weather, it would be possible to maintain speed at the expense of some sensitivity, i.e. by increasing the MRS by one level of signal strength in μv.

The surveys described were limited to within a fathom of the bottom. Thus they describe the distribution of catchable fish. However, from the study of the catch-signal relation, it will be seen that we were unable to distinguish fish which swam below the depth of the headline from those which swam above it and so were not caught. Such signals from fish above the headline are sometimes recorded on the paper record.

VI. GENERAL CONCLUSIONS

General Conclusions

The work described above arose from the need to survey cod populations on the bottom of the Barents Sea. Such surveys implied that the echo sounder could be used quantitatively; to put it another way, it was assumed that variations in abundance were considerably greater than variations in power output, in water noise and in the electrical characteristics of the instrument. The experimental work described above justifies this assumption.

The main argument is as follows:

1. By counting fish echoes on the CRT, a relationship was established between the catch in baskets of cod and the total voltage received from fish whilst the trawl was fishing. On the basis of this relationship, a survey method was developed which showed the movement of the cod population on to the banks between Bear Island and Spitzbergen in a period of about ten days; the movement was correlated with the movement of warm water on to the banks.

2. Signals from single dead fish were measured and it was found that a single cod of 80–90 cm was detectable (on the axis of transmission) down to 170 fathoms when towing and to 300 fathoms when steaming at 10 knots. A 20 cm cod could be detected at 20 fathoms when towing and at 50 fathoms when steaming at 10 knots. For fish of between 20 cm and 80 cm, there was a roughly linear relationship between received signal and length (30 μv were received from a 20 cm cod and 230 μv were received from an 80 cm cod). A reasonable approximation is that a 70 cm cod gives the same signal as an 8″ diameter steel trawl float.

3. A weight was dragged on a wire by the drifting ship over the bottom and from the wire a trawl float was tied two fathoms from the weight. As the wire angle increased, the signal from the trawl float on the CRT moved towards the bottom signal and merged with it. The true height of the float from the bottom was approximately known, its apparent height was measured on the CRT and the true depth of water was known. From these measurements the angle made by the float to the transducer was calculable and then amplitude, measured on the CRT in μv, was plotted against this angle. From such regressions, it was possible to calculate a "standard signal" from the trawl float, as at one fathom from the transducer on the axis ($1{\cdot}9\times 10^5$ μv). An analysis of fingernail traces from single fish (probably 60 cm cod) at different depths yielded an estimate of the "standard signal" of $1{\cdot}5\times 10^5$ μv, which is very close to that measured from the trawl float.

4. The quantitative use of the echo sounder is new. The three sets of experiments described in this paper, on the catch/signal relation, on signals from single fish and on the correspondence of the "standard signal" as measured from a trawl float and as estimated from single fish traces, lead us to conclude that there is reasonable justification for treating the echo sounder as a quantitative instrument. To obtain these results, variations in power output, in water noise and in the electrical characteristics of the instrument, must have been comparatively small.

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R. W. Blacker

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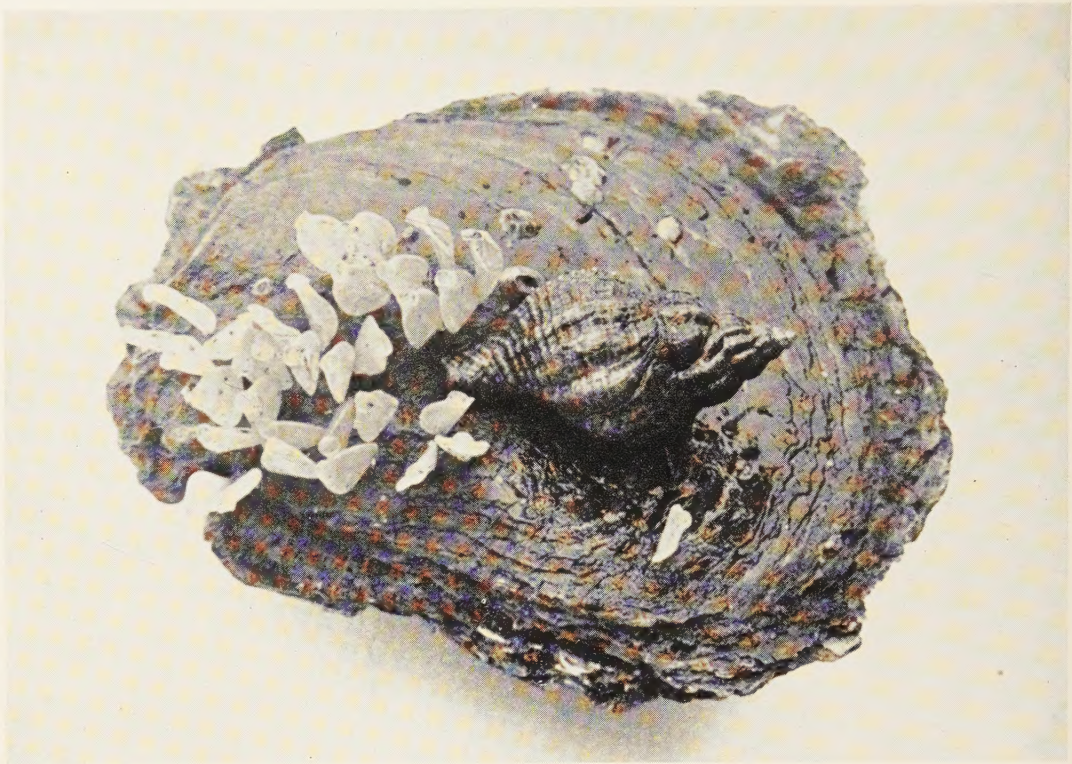
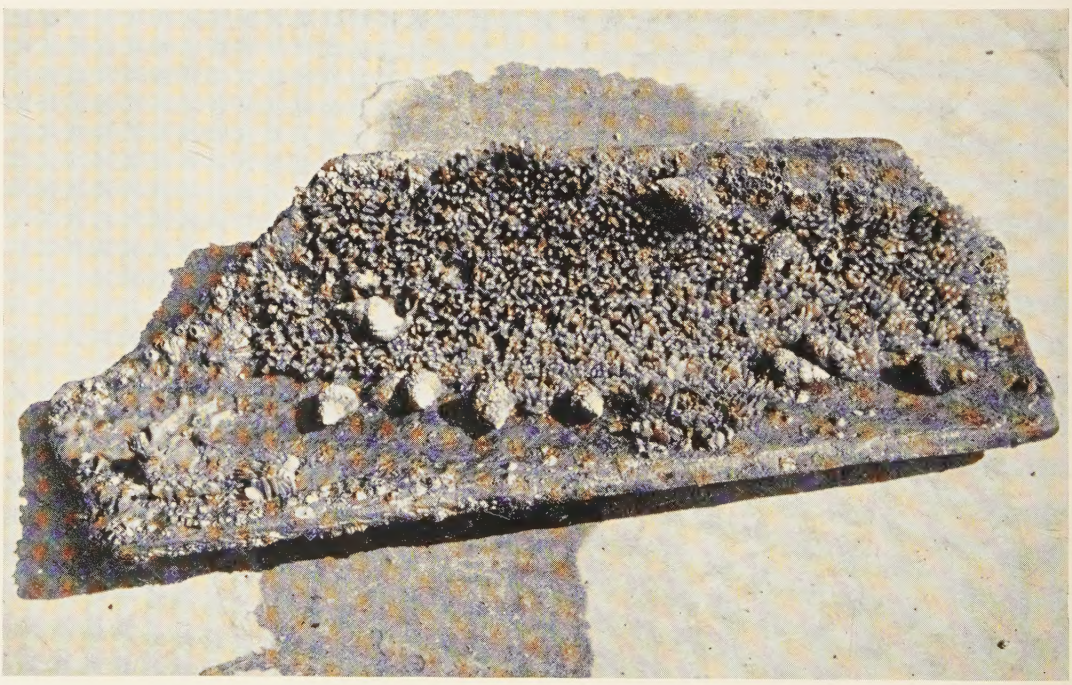


A female Urosalpinx *depositing spawn capsules on the shell of an adult oyster.* (*X* 5/3).
Photo: P. J. Warren



The underside of a curved roofing tile used as a trap for Urosalpinx
and its spawn at the Common Shore, R. Roach. (*X* 2/7).
Photo: P. J. Warren